

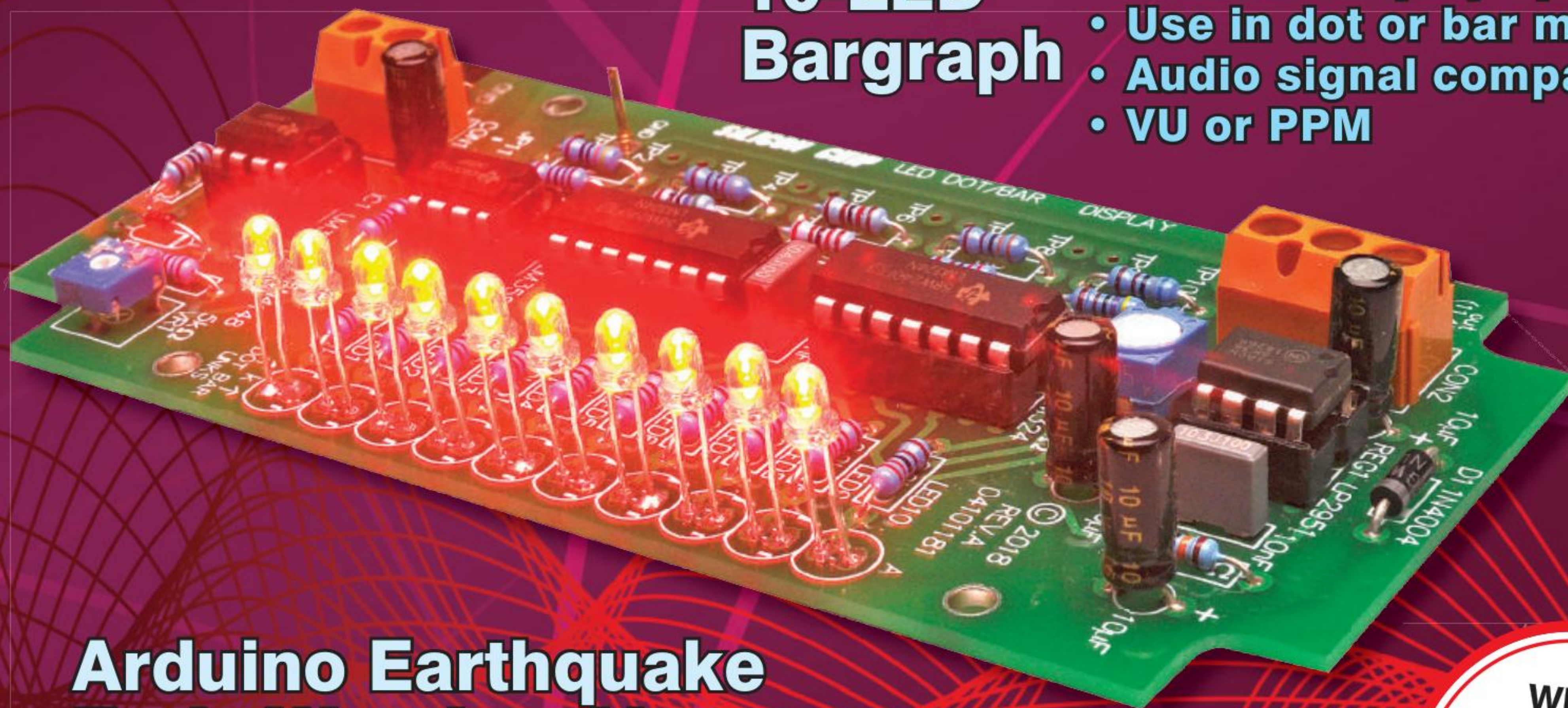
THE No 1 UK MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

EPE EVERYDAY PRACTICAL ELECTRONICS

www.epemag.com

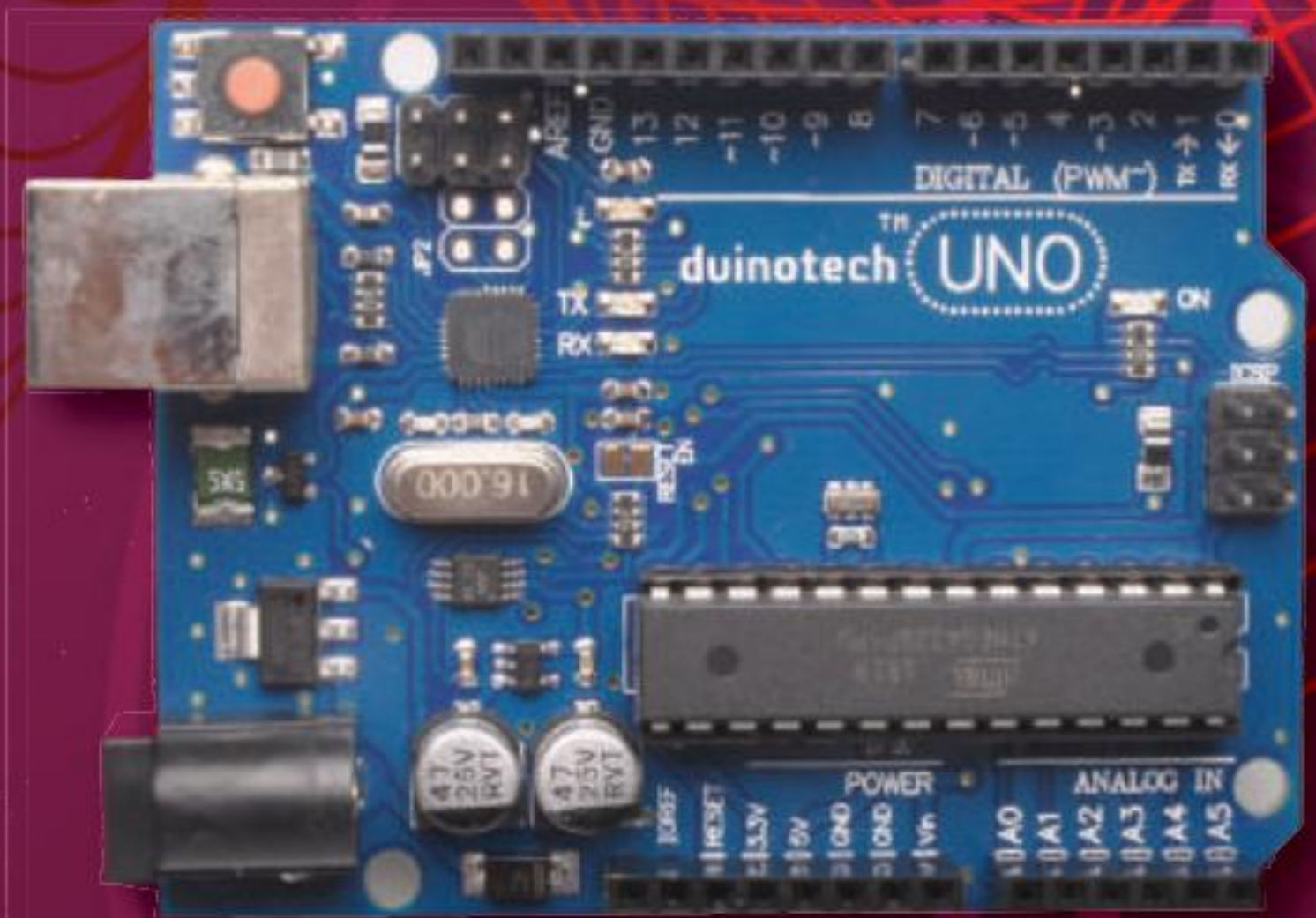
10-LED Bargraph

- Flexible display options
- Use in dot or bar mode
- Audio signal compatible
- VU or PPM



Arduino Earthquake Early Warning Alarm

Build this fascinating system!



WIN A
MICROCHIP
MPLAB PICKIT 4
In-Circuit
Debugger



Teach-In 2019

Powering Electronics

Part 4: Switched-mode power supplies

MIDI Ultimate Synthesiser – Part 2

Power, VCOs, VCF and mixer

AUDIO OUT | TECHNO TALK | CIRCUIT SURGERY
ELECTRONIC BUILDING BLOCKS | NET WORK
MAKE IT WITH MICROMITE | COOL BEANS | PIC n' MIX

MAR 2019 £4.65



With Over 250 Million Units in Stock, We've Got You Covered

Delivering You the World's Largest Inventory of Microchip Products



www.microchip.com/learn-more



The Microchip name and logo and the Microchip logo are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.
All other trademarks are the property of their registered owners.
© 2018 Microchip Technology Inc. All rights reserved. DS00002552A. MEC2226Eng10/18

Projects and Circuits

10-LED BARGRAPH

by John Clarke

Want a really flexible bargraph? This 10-LED display works in dot or bar mode, and for audio signal monitoring provides VU or Peak Program Metering (PPM).

EARTHQUAKE EARLY WARNING ALARM

by Allan Linton-Smith (concept) and Nicholas Vinen (circuit and software)

Earthquakes can strike anywhere. This Arduino-based, low-cost and easy-to-build project gives advanced warning of danger.

USING CHEAP ASIAN ELECTRONIC MODULES – PART 14

by Jim Rowe

Learn to use Banggood's RF Detector module.

MIDI ULTIMATE SYNTHESIZER – PART 2

by Paul Cooper

Construction continues with the power supply and sections of the main PCB.

Series and Features

TECHNO TALK by Mark Nelson

When will they learn?

NET WORK by Alan Winstanley

Alan Winstanley peers through cracks in the paperless revolution, connects with Google Home Mini and looks forward to the (re)launch of Practical Electronics.

TEACH-IN 2019 – POWERING ELECTRONICS

Part 4: Switched-mode power supplies

MAX'S COOL BEANS by Max The Magnificent

Audio-reactive artifacts... A tangle of wires... Decisions, decisions

AUDIO OUT by Jake Rothman

Low-level power supplies in audio systems – Part 2

CIRCUIT SURGERY by Ian Bell

MOSFET power switches – Part 1

PIC n' MIX by Mike Hibbett

Building circuits with SMDs – Part 2

MAKE IT WITH MICROMITE by Phil Boyce

Part 2 – Building the Micromite Keyring Computer

ELECTRONIC BUILDING BLOCKS by Julian Edgar

K-Type Thermocouple Display

Regulars and Services

SUBSCRIBE TO EPE AND SAVE MONEY

EDITORIAL

Everyday Practical Electronics... Au revoir – not 'goodbye'

EPE BACK ISSUES CD-ROM – GREAT 15-YEAR DEAL!

NEWS

EPE TEACH-IN BUNDLE – WHAT A BARGAIN!

MICROCHIP READER OFFER

EPE Exclusive – Win a Microchip MPLAB PICkit 4 In-Circuit Debugger

EPE TEACH-IN 9

EPE TEACH-IN 8

EPE CD-ROMS FOR ELECTRONICS

A wide range of CD-ROMs for hobbyists, students and engineers

DIRECT BOOK SERVICE

A wide range of technical books available by mail order, plus more CD-ROMs

EPE PCB SERVICE

PCBs for EPE projects

ADVERTISERS INDEX

NEXT MONTH! – Highlights of next month's EPE

Readers' Services • Editorial and Advertisement Departments

© Electron Publishing Limited 2019. Copyright in all drawings, photographs and articles published in *EVERYDAY PRACTICAL ELECTRONICS* is fully protected, and reproduction or imitations in whole or in part are expressly forbidden.

Our April 2019 issue will be published on Thursday 7 March 2019, see page 80 for details.



Quasar Electronics Limited
PO Box 6935, Bishops Cleeve
CM23 4WP, United Kingdom

Tel: 01279 467799
E-mail: sales@quasarelectronics.co.uk
Web: quasarelectronics.co.uk

All prices INCLUDE 20.0% VAT. Free UK delivery on orders over £48
Postage & Packing Options (Up to 0.5Kg gross weight): UK Standard 3-7
Day Delivery - £4.95; UK Mainland Next Day Delivery - £9.95; Europe
(EU) - £12.95; Rest of World - £14.95 (up to 0.5Kg).
!! Order online for reduced price postage and fast despatch !!
Payment: We accept all major credit/debit cards. Make cheques/PO's
payable to Quasar Electronics Limited.
Please visit our online shop now for full details of over 1000 electronic
kits, projects, modules and publications. Discounts for bulk quantities.



QuasarElectronics.co.uk

Solutions for Home, Education & Industry Since 1993



Official Main Dealer stocking the full range of Kits, Modules, Robots, Instruments, tools and much, much more...

PIC & ATMEL Programmers

We have a wide range of PIC, ATMEL Arduino and Raspberry Pi projects.

PIC Programmer & Experimenter Board

Great learning tool. Includes programming examples and a reprogrammable 16F627 Flash Microcontroller. Test buttons & LED indicators. Software to compile & program your source code is included. Supply: 12-15Vdc. Pre-assembled and ready to use.
Order Code: VM111 - ~~£38.88~~ **£35.94**



USB PIC Programmer and Tutor Board

The only tutorial project board you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. Programs all the devices a Microchip PICKIT2[®] can! Use the free Microchip tools for PICKIT2[™] & MPLAB[®] IDE environment.
Order Code: EDU10 - **£46.74**



USB /Serial Port PIC Programmer

Fast programming. Wide range of PICs supported (see website for details). Free Windows software & ICSP header cable. USB or Serial connection. ZIF Socket, leads, PSU not included.
Kit Order Code: 3149EKT - ~~£49.96~~ **£29.95**
Assembled Order Code: AS3149E - **£44.95**
Assembled with ZIF socket Order Code: AS3149EZIF - ~~£74.96~~ **£49.95**



PICKIT[™]2 USB PIC Programmer Module

Versatile, low cost, PICKIT[™]2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header. USB powered.
Assembled Order Code: VM203 - **£35.94**



Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
Kit Order Code: K8055N - ~~£39.95~~ **£22.20**
Assembled Order Code: VM110N - **£35.94**



2-Channel High Current UHF RC Set

State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 12 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx. Kit includes one Tx (more available separately). 9-15Vdc.
Kit Order Code: 8157KT - **£44.95**
Assembled Order Code: AS8157 - **£49.96**



Computer Temperature Data Logger

Serial port 4-ch temperature logger. °C/°F. Continuously log up to 4 sensors located 200m+ from board. Choice of free software applications downloads for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS18S20 sensor.
Kit Order Code: 3145KT - ~~£19.95~~ **£16.97**
Assembled Order Code: AS3145 - **£19.96**
Additional DS18S20 Sensors - **£4.96 each**



8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers... Test software & DLL online.
Assembled Order Code: VM201 - **£130.80**



Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - **£15.26**
Assembled Order Code: AS3179 - **£22.26**



Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/5A) in both the forward and reverse directions. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections. PCB: 90x42mm.
Kit Order Code: 3166KT - **£19.99**
Assembled Order Code: AS3166 - **£29.99**



8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our free Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc, 500mA.
Kit Order Code: 3108KT - **£74.95**
Assembled Order Code: AS3108 - **£89.95**



8-Channel RF Remote Control Set

Control 8 onboard relays with included RF remote control unit. Toggle or momentary mode for each output. Up to 50m range. Board Supply: 12Vac, 500mA
Assembled Order Code: VM118 - **£71.94**



Temperature Monitor & Relay Controller

Computer serial port temperature monitor & relay controller. Accepts up to four Dallas DS18S20 / DS18B20 digital thermometer sensors (1 included). Four relay outputs are independent of the sensors giving flexibility to setup the linkage any way you choose. Commands for reading temperature / controlling relays are simple text strings sent using a simple terminal or coms program (e.g. HyperTerminal) or our free Windows application. Supply: 12Vdc.
Kit Order Code: 3190KT - ~~£79.96~~ **£47.95**
Assembled Order Code: AS3190 - **£59.95**



3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone or 2-wire serial interface for microcontroller or PC communication with simple command set. Suits common anode RGB LED strips, LEDs, incandescent bulbs. 12A total max. Supply: 12Vdc. 69x56x18mm
Kit Order Code: 8191KT - **£24.95**
Assembled Order Code: AS8191 - **£27.95**



**Card Sales
& Enquiries**

**01279
467799**



www.Soundtronics.co.uk

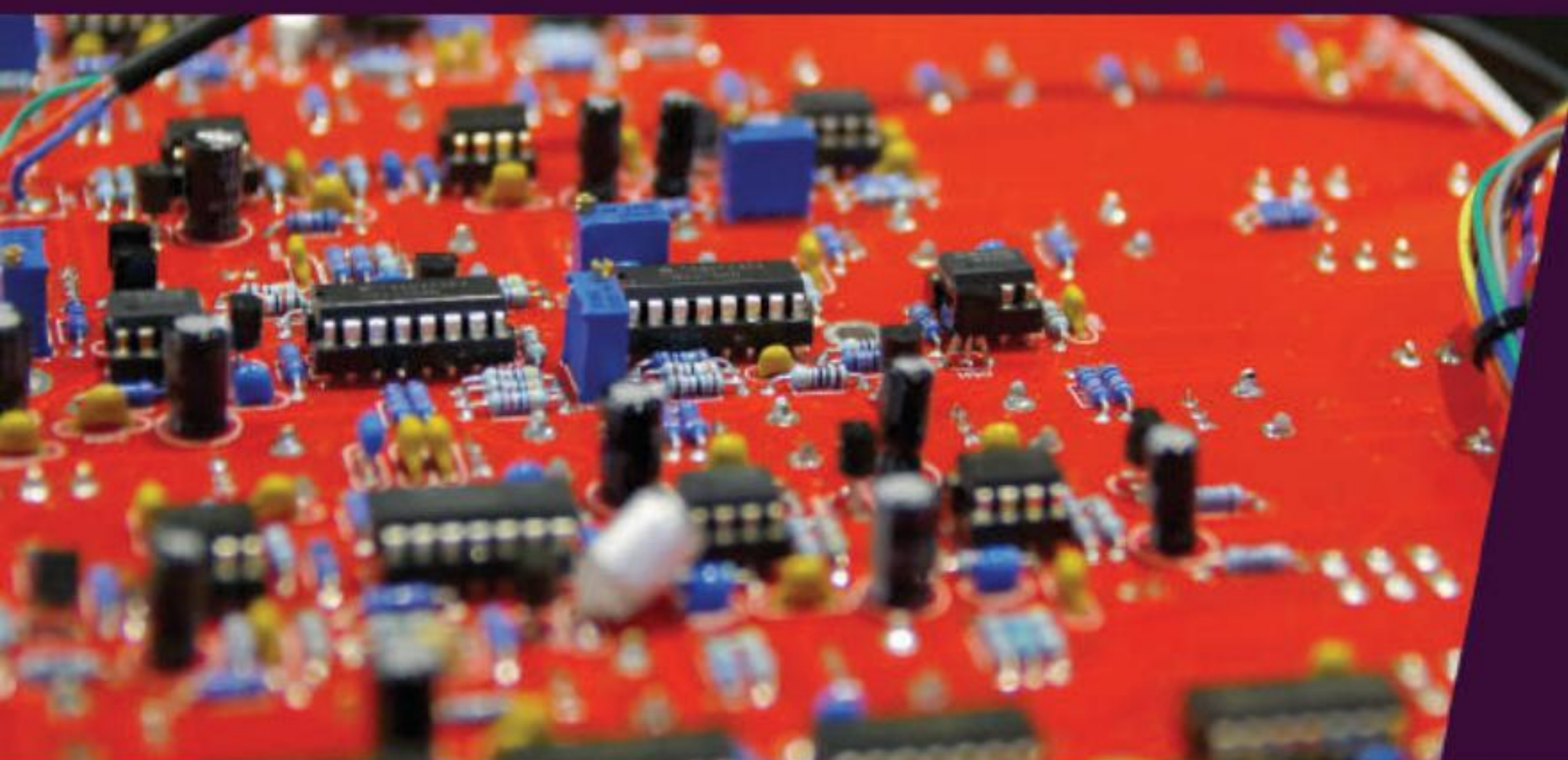


MIDI Ultimate Analogue Synth Kits

As Featured In

EPE EVERYDAY PRACTICAL ELECTRONICS

60+ analogue synth module kits are available with our matching 5U format front panels, based on the renowned MFOS and YuSynth designs. Kits range from VCO's to 16 step analogue sequencers



A range of 5 single board synths available, each with essential modular synth functions. All built into a compact enclosure, including the popular MFOS Sound Lab Ultimate

Manufactured in-house, our attractive hardwood modular cabinets and desktop cases are a great way to complete your build. Available in maple, oak and walnut timbers.

MIDI Ultimate

- Parts & complete kits
- Front panels
- Hardwood case

Available at soundtronics



Over 1,000 products to choose from including kits, PCB's and individual components



facebook.com/SoundtronicsUK
www.soundtronics.co.uk

UK readers you can **SAVE 73p** on every issue of *EPE*

How would you like to pay £3.92 instead of £4.65 for your copy of *EPE*?



Well you can – just take out a one year subscription and save **73p** an issue, or **£8.80** over the year. You can even save **94p** an issue if you subscribe for two years – a total saving of **£22.60**

Overseas rates also represent exceptional value

You also:

- Avoid any cover price increase for the duration of your subscription
- Get your magazine delivered to your door each month
- Ensure your copy, even if the newsagents sell out

Order by phone, or fax with a credit card, or by post with a cheque or postal order, or buy online from www.epemag.com (go to the Online Shop).



SUBSCRIPTION PRICES

Subscriptions for delivery direct to any address in:

UK: 6-months £25.00, 12-months £47.00, 24-months £89.00;

Europe Airmail: 6-months £30.00, 12-months £56.00, 24-months £107.00;

Rest Of The World Airmail: 6-months £37.00, 12-months £70.00, 24-months £135.00.

Cheques or bank drafts (in **£ sterling only**) payable to *Everyday Practical Electronics* and sent to EPE Subs. Dept., Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU.

Tel: 01202 880299. **Fax:** 01202 843233.

Email: fay.kearn@wimborne.co.uk.

Also via our secure online shop at: www.epemag.com.

Subscriptions start with the next available issue. We accept MasterCard or Visa.

(For past issues see the Back Issues page.)



ONLINE SUBSCRIPTIONS

Online subscriptions, for reading the magazine via the Internet, £22.00 for one year, visit www.epemag.com for more details.

SUBSCRIPTION ORDER FORM

- ☐ 6 Months: UK £25.00, Europe £30.00 (Airmail), Rest of the World £37.00 (Airmail)
- ☐ 1 Year: UK £47.00, Europe £56.00 (Airmail), Rest of the World £70.00 (Airmail)
- ☐ 2 Years: UK £89.00, Europe £107.00 (Airmail), Rest of the World £135.00 (Airmail)

To: Everyday Practical Electronics
Wimborne Publishing Ltd
113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU
Tel: 01202 880299 **Fax:** 01202 843233
Email: fay.kearn@wimborne.co.uk

I enclose payment of £
(cheque/PO in £ sterling only)
payable to *Everyday Practical Electronics*

☐ Please charge my Visa/Mastercard

My card number is:
Please print clearly, and check that you have the number correct

Signature

Card Security Code Valid From Date.....
(The last 3 digits on or just under the signature strip)

Card Ex. Date

Name

Address

Post code Tel.

Subscriptions can only start with the next available issue.





Accelerate Your Design With Our Comprehensive Ecosystem

We Have What You Need, When You Need It

Looking for the fastest, simplest and lowest-risk path from prototype to production? Microchip offers you complete design support for every stage of your project with our complete development ecosystem.

- Build prototypes quickly with an intuitive design and debugging environment
- Jump-start your project with reference designs and application-specific hardware
- Lower your risk with proven tools and professionally tested software

No matter your needs, we offer you complete design support at every stage of your project.



Start developing now at
www.microchip.com/Ecosystem



**- EPE -
NEW NAME
NEW DESIGN!**

Practical Electronics

It's time for a spring clean at *EPE*. From the April 2019 issue your magazine will have a fresh new look and a fresh new title – *Practical Electronics*.

The price, pagination, contributors and quality will stay the same. All your favourites, from *PIC n' Mix* and *Circuit Surgery* to *Audio Out* and *Net Work* will still be there – but in a smart new livery.

Wherever you buy your copy of the UK's premier electronics magazine, look for the new title and design!



The UK's premier electronics and computing maker magazine

Audio Out
Powering
audio circuits

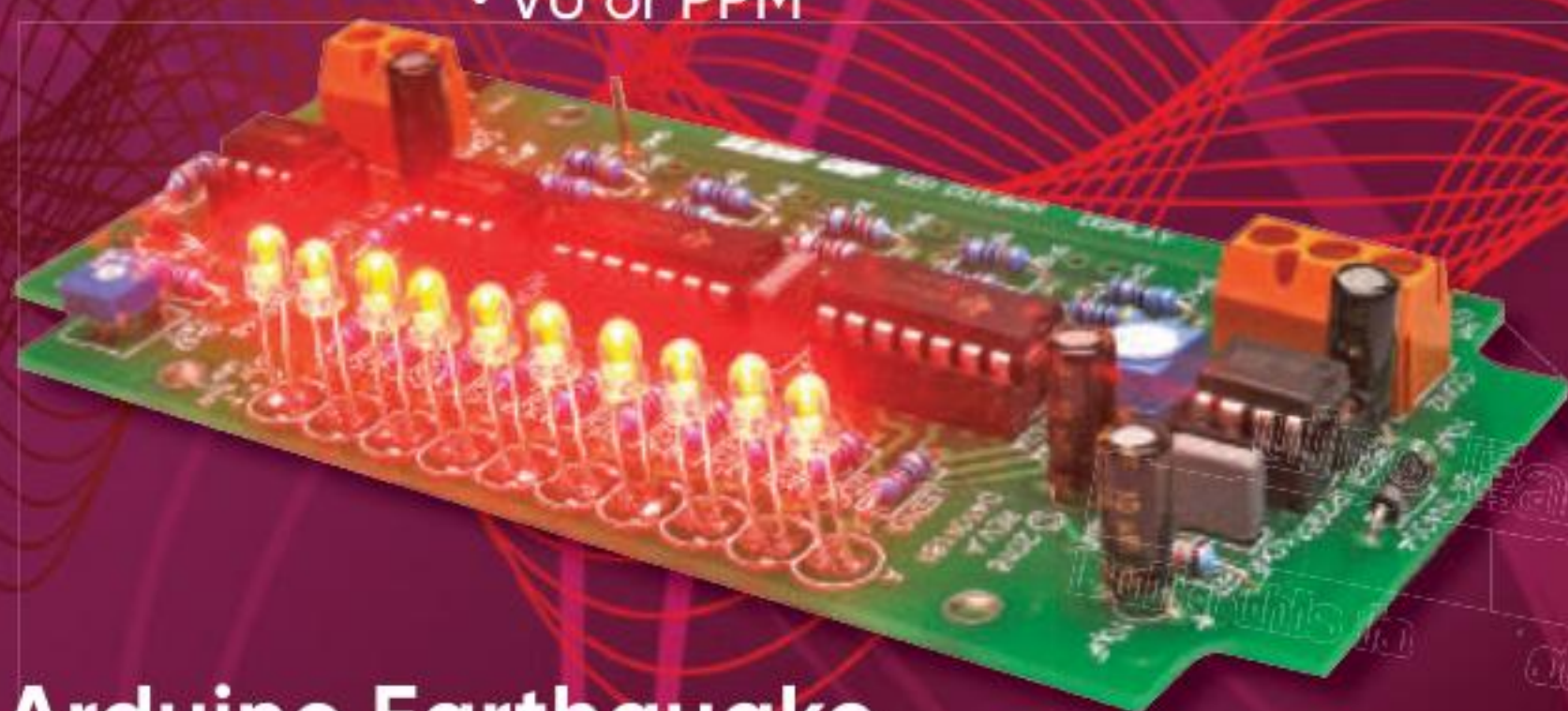
Circuit Surgery
MOSFET power
switches

Net Work
Paperless office
Google Home Mini

PIC n' Mix
Building circuits
with SMDs

10-LED Bargraph

- Flexible display options
- Use in dot or bar mode
- Audio signal compatible
- VU or PPM



WIN A
MICROCHIP
MPLAB PICKIT 4
In-Circuit
Debugger

Arduino Earthquake Early Warning Alarm



MIDI Ultimate Synthesiser – Part 2

Power, VCOs, VCF and mixer

PLUS!

Make it with Micromite
TEACH-IN 2019 – Powering Electronics
RF Detector module

Mar 2019 £4.65



www.epemag.com | #epemag | facebook | instagram | LinkedIn

EVERYDAY PRACTICAL ELECTRONICS

- Flexible display options
- Use in dot or bar mode
- Audio signal compatible
- VU or PPM



WIN A
MICROCHIP
MPLAB PICKIT 4
In-Circuit
Debugger



MIDI Ultimate Synthesiser – Part 2

Power, VCOs, VCF and mixer

MAR 2019 £4.65



Editorial offices

Everyday Practical Electronics
Electron Publishing Limited
1 Buckingham Road
Brighton
East Sussex BN1 3RA

Phone 01273 777619
07973 518682
Fax 01202 843233
Email fay.kearn@wimborne.co.uk
Website www.epemag.com

Advertisement offices

Everyday Practical Electronics Advertisements
1 Buckingham Road
Brighton
East Sussex BN1 3RA

Phone 01273 777619
Fax 01202 843233
Email stewart.kearn@wimborne.co.uk

Editor Matt Pulzer
General Manager Louisa Pulzer
Subscriptions Stewart Kearns
On-Line Editor Alan Winstanley
Publisher Matt Pulzer

Technical enquiries

Email: fay.kearn@wimborne.co.uk

We regret technical enquiries cannot be answered over the telephone. We are unable to offer any advice on the use, purchase, repair or modification of commercial equipment or the incorporation or modification of designs published in the magazine. We regret that we cannot provide data or answer queries on articles or projects that are more than five years' old. Letters requiring a personal reply must be accompanied by a stamped self-addressed envelope or a self-addressed envelope and international reply coupons. We are not able to answer technical queries on the phone.

Projects and circuits

All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

Component supplies

We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers. We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

Advertisements

Although the proprietors and staff of Everyday Practical Electronics take reasonable precautions to protect the interests of readers by ensuring as far as practicable that advertisements are bona fide, the magazine and its publishers cannot give any undertakings in respect of statements or claims made by advertisers, whether these advertisements are printed as part of the magazine, or in inserts. The Publishers regret that under no circumstances will the magazine accept liability for non-receipt of goods ordered, or for late delivery, or for faults in manufacture.

Transmitters/bugs/telephone equipment

We advise readers that certain items of radio transmitting and telephone equipment which may be advertised in our pages cannot be legally used in the UK. Readers should check the law before buying any transmitting or telephone equipment, as a fine, confiscation of equipment and/or imprisonment can result from illegal use or ownership. The laws vary from country to country; readers should check local laws.

EPE EVERYDAY PRACTICAL ELECTRONICS

Everyday Practical Electronics

Welcome to the final issue of *Everyday Practical Electronics*! Just in case that sounds a little dramatic, rest assured that this is not the end of your magazine – quite the opposite. I hope you are not too bored of me reminding you that next month's issue – April 2019 – will be the first under our new name of *Practical Electronics (PE)*. If you are a subscriber you don't need to do anything – your magazine will arrive exactly as before. However, if you enjoy buying your magazine in a newsagent, then do look out for our new-style cover (see opposite). Newsagents and stockists should position *PE* in the same place as *EPE*, but do ask if you can't find it. Better still, why not take out a subscription and ensure you never miss a copy, and save some money into the bargain.

Practical Electronics online

Transferring and redesigning *EPE/PE* has taken up most of our bandwidth over the last few months, but between now and the summer we will turn our attention to the website. That does mean for a short period *PE* will effectively have an *EPE* website. Not ideal, but I'm sure you'd rather we got things right rather than rush into a hastily planned and poorly executed change. The 'current' website remains fully operational and if you want to buy books, PCBs, software or back issues, or take out / renew a subscription then you will see no change. In fact, you will even be dealing with the same person. Stewart Kearns, who managed Wimborne Publishing until I took over, has agreed to continue running the *EPE* online shop until our new *PE* website is up and running smoothly. Long version, short – do please continue to visit and use **www.epemag.com** with confidence.

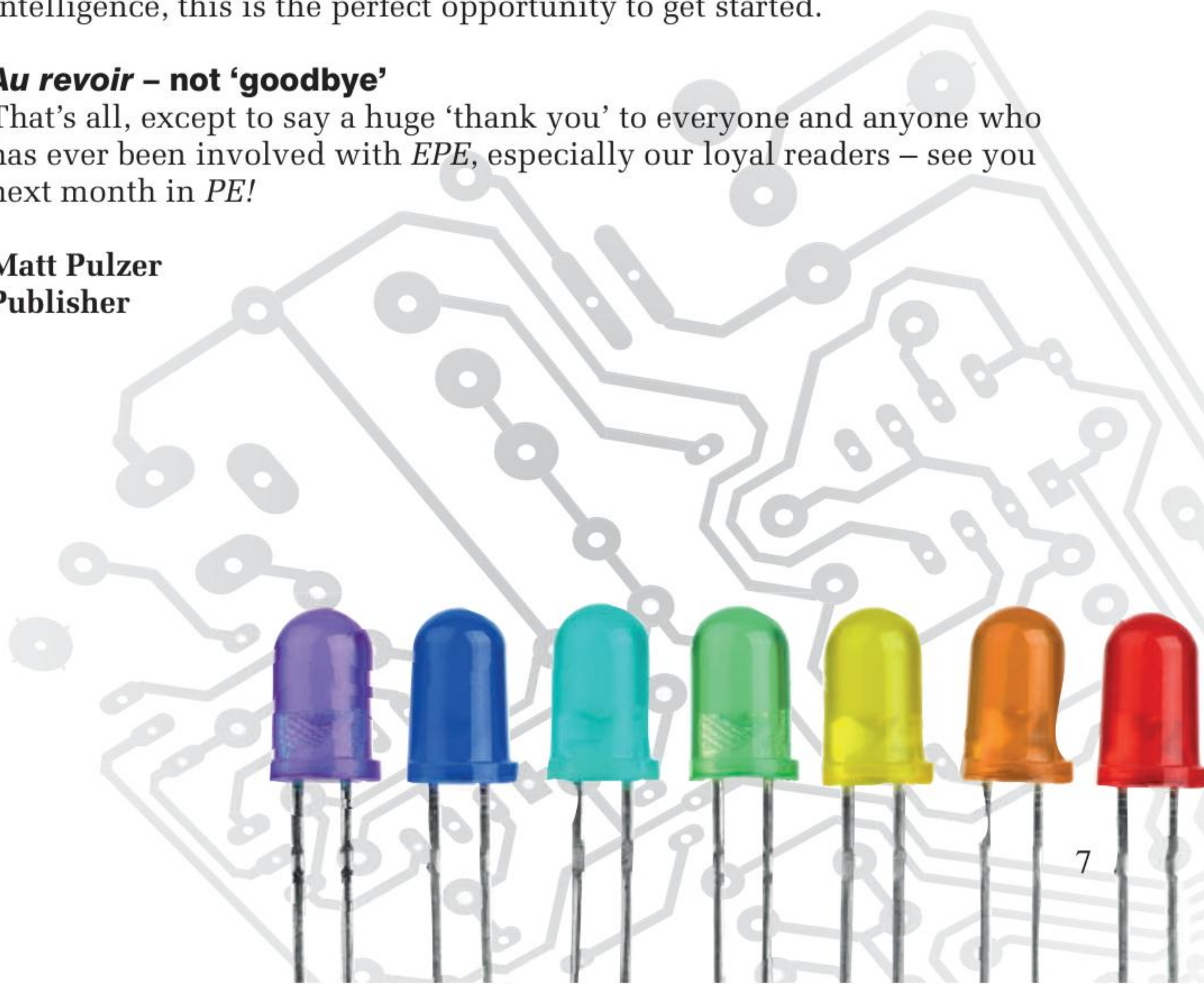
Micromite fun

We have a great issue for you this month. I only have space to highlight one column here, and I've chosen Phil Boyce's new series on the Micromite. In *Part 2* it really starts to take shape with a thorough description of how to build the *Micromite Keyring Computer*. This is a must for anyone who wants to start building microcontroller-based projects. Even better, this is a series that is definitely open to home constructors of all experience levels – no SMDs, no multi-layer PCBs; just a handful of inexpensive through-hole devices and some stripboard. So, if you've never built a circuit that incorporates some kind of digital intelligence, this is the perfect opportunity to get started.

Au revoir – not 'goodbye'

That's all, except to say a huge 'thank you' to everyone and anyone who has ever been involved with *EPE*, especially our loyal readers – see you next month in *PE*!

Matt Pulzer
Publisher



STORE YOUR BACK ISSUES ON CD-ROMS

Order on-line from
www.epemag.com (go to the UK store)
 or by phone, fax, email or post

- VOL 1:** **BACK ISSUES** – January 1999 to June 1999
 Plus some bonus material from Nov and Dec 1998
- VOL 2:** **BACK ISSUES** – July 1999 to December 1999
- VOL 3:** **BACK ISSUES** – January 2000 to June 2000
- VOL 4:** **BACK ISSUES** – July 2000 to December 2000
- VOL 5:** **BACK ISSUES** – January 2001 to June 2001
- VOL 6:** **BACK ISSUES** – July 2001 to December 2001
- VOL 7:** **BACK ISSUES** – January 2002 to June 2002
- VOL 8:** **BACK ISSUES** – July 2002 to December 2002
- VOL 9:** **BACK ISSUES** – January 2003 to June 2003
- VOL 10:** **BACK ISSUES** – July 2003 to December 2003
- VOL 11:** **BACK ISSUES** – January 2004 to June 2004
- VOL 12:** **BACK ISSUES** – July 2004 to December 2004
- VOL 13:** **BACK ISSUES** – January 2005 to June 2005
- VOL 14:** **BACK ISSUES** – July 2005 to December 2005
- VOL 15:** **BACK ISSUES** – January 2006 to June 2006
- VOL 16:** **BACK ISSUES** – July 2006 to December 2006
- VOL 17:** **BACK ISSUES** – January 2007 to June 2007
- VOL 18:** **BACK ISSUES** – July 2007 to December 2007
- VOL 19:** **BACK ISSUES** – January 2008 to June 2008
- VOL 20:** **BACK ISSUES** – July 2008 to December 2008
- VOL 21:** **BACK ISSUES** – January 2009 to June 2009
- VOL 22:** **BACK ISSUES** – July 2009 to December 2009

NOTE: These DVD/CD-ROMs are suitable for use on any PC with a DVD/CD-ROM drive. They require Adobe Acrobat Reader (available free from the Internet – www.adobe.com/acrobat)

ONLY
£16.45
 (£29.95 FOR 5 YEAR)
 each including VAT and p&p



- VOL 23:** **BACK ISSUES** – January 2010 to June 2010
- VOL 24:** **BACK ISSUES** – July 2010 to December 2010
- VOL 25:** **BACK ISSUES** – January 2011 to June 2011
- VOL 26:** **BACK ISSUES** – July 2011 to December 2011
- VOL 27:** **BACK ISSUES** – January 2012 to June 2012
- VOL 28:** **BACK ISSUES** – July 2012 to December 2012
- VOL 29:** **BACK ISSUES** – January 2013 to June 2013
- VOL 30:** **BACK ISSUES** – July 2013 to December 2013
- VOL 31:** **BACK ISSUES** – January 2014 to June 2014
- VOL 32:** **BACK ISSUES** – July 2014 to December 2014
- VOL 33:** **BACK ISSUES** – January 2015 to June 2015
- VOL 34:** **BACK ISSUES** – July 2015 to December 2015
- VOL 35:** **BACK ISSUES** – January 2016 to June 2016
- VOL 36:** **BACK ISSUES** – July 2016 to December 2016
- VOL 37:** **BACK ISSUES** – January 2017 to June 2017
- VOL 38:** **BACK ISSUES** – July 2017 to December 2017

NEW
Vol.39

VOL 39: BACK ISSUES –
 January 2018 to June 2018

FIVE YEAR DVD/CD-ROMs

FIVE YEAR CD/DVD-ROMs

- No.1** – Jan '03 to Dec '07
- No.2** – Jan '04 to Dec '08
- No.3** – Jan '05 to Dec '09
- No.4** – Jan '06 to Dec '10
- No.5** – Jan '07 to Dec '11
- No.6** – Jan '08 to Dec '12
- No.7** – Jan '09 to Dec '13
- No.8** – Jan '10 to Dec '14
- No.9** – Jan '11 to Dec '15
- No.10** – Jan '12 to Dec '16

No.11 – Jan '13 to Dec '17

NEW
Vol.11



FIVE YEAR DVD-ROMs BUNDLE OFFER

**15 YEARS OF EPE AT
 A GREAT PRICE**

No.1 – Jan '03 to Dec '07

No.6 – Jan '08 to Dec '12

No.11 – Jan '13 to Dec '17

**ONLY AN AMAZING
 £39.95**

NEWS

A roundup of the latest news from the world of electronics

Fingernail sensor health monitor

Grip strength is a useful metric in a surprisingly broad set of health issues; for example the effectiveness of medication with Parkinson's disease or the state of an individual's cardiovascular health.

At IBM Research, a team is working on a 'fingernail sensor' to help monitor human health. The wearable, wireless device continuously measures how a person's fingernail bends and moves, which is a key indicator of grip strength.

One of the functions of human fingernails is to focus the finger-tip pulp on the object being manipulated. Fingernails deform – bend and move – in predictable ways when we use them for gripping, grasping, and even flexing and extending our fingers. This deformation is usually on the order of single-digit microns and not visible to the naked eye (a human hair is between 50 and 100 microns across). However, it can be easily detected with strain gauge sensors.

IBM's system consists of strain gauges attached to the fingernail and a small computer that samples strain values, collects accelerometer data and communicates with a smart watch. The watch also runs machine-learning models to rate bradykinesia, tremor, and dyskinesia, which are all symptoms of Parkinson's disease.

The combination of precision sensing and AI analysis means that it is possible to interpret subtle finger movements from nail deformation. The system can differentiate typical



daily activities which all involve pronation and supination such as turning a key, opening a doorknob or using a screwdriver. An even more subtle activity is finger writing, and a trained neural network produced very good accuracy (.94) at detecting digits written by a finger wearing the sensor.

This work has also inspired a new device modelled on the structure of the fingertip that could one day help quadriplegics communicate.

Electrical bacteria

Microbes under study at the Massachusetts Institute of Technology have been found to produce electricity. They live in oxygen-deprived environments, which means they need a way to breathe that doesn't involve oxygen. These hardy microbes, which can be found deep in mines, the bottom of lakes or even the human gut have evolved a unique form of 'breathing' that involves excreting and pumping out electrons.

Researchers are exploring how to harness these microbial power plants to run fuel cells and purify sewage water.

UK graphene research accelerates

A team of researchers based at The University of Manchester, working with the National Physical Laboratory, has found a brand new low-cost method for producing graphene printed electronics, which results in significantly faster and cheaper conductive graphene inks. Graphene is an important material for researchers because it has the potential to create the next generation of electronics, currently limited to science fiction: from faster transistors to bendable phones and flexible wearable electronics.

Printed electronics offers a breakthrough in the penetration of information technology into everyday life, especially Internet of Things (IoT) applications. As a result, the development of printed conduc-

tive inks for electronic applications has grown rapidly, widening applications for transistors, sensors, antennas, RFID tags and 'wearables'.

Current conductive inks traditionally use metal nanoparticles for their high electrical conductivity, but these materials can be expensive or easily oxidised, making them far from ideal for low-cost IoT applications. The team has found that using a material called 'dihydrolevoglucosenone' (known as 'Cyrene') which is non-toxic, environmentally friendly and sustainable can provide higher concentrations and conductivity when using low-cost graphene ink.

The hope is that the discovery will help to unite the electronics potential of graphene with inexpensive printing technology.



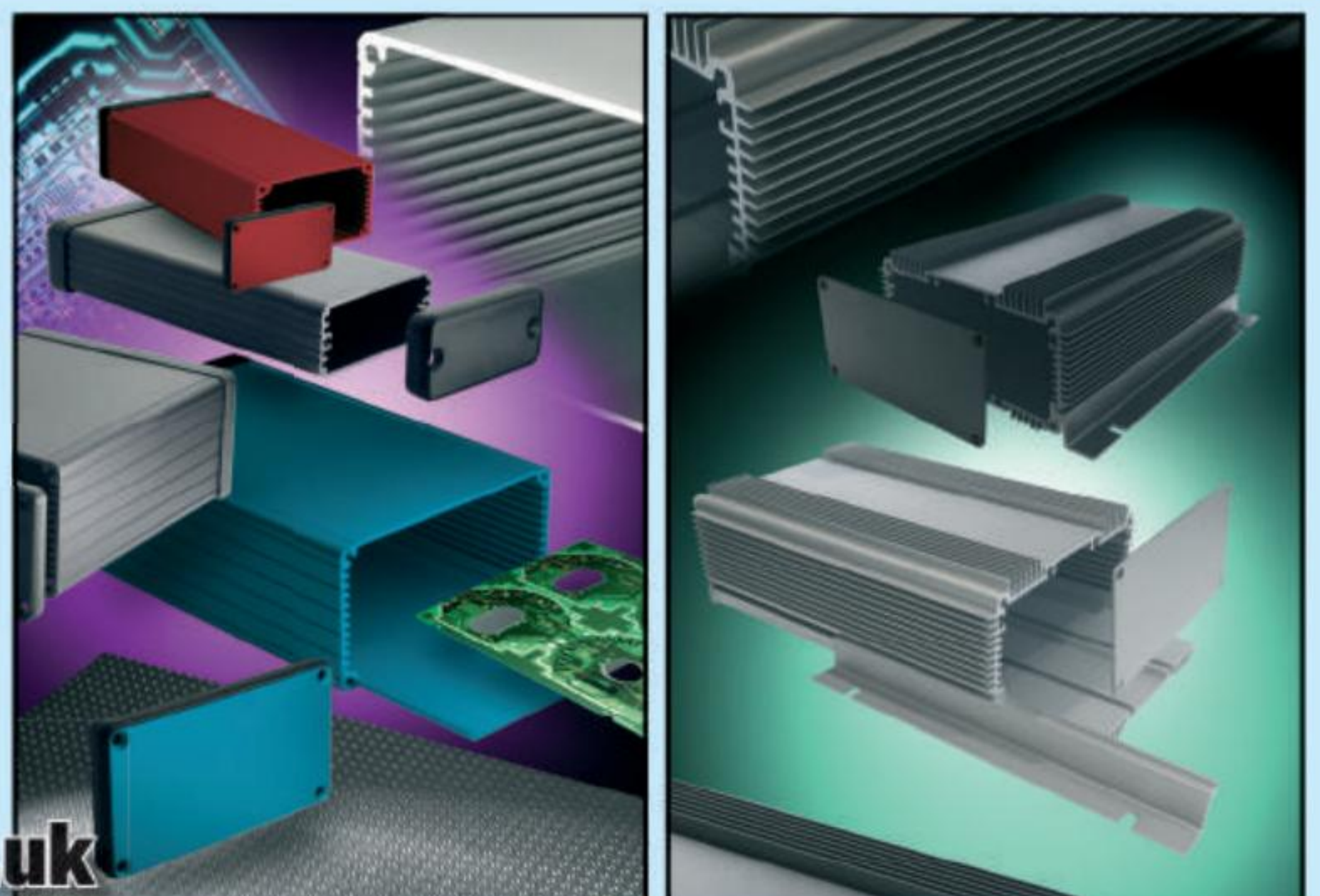
**Extruded enclosures
standard and heatsink**

www.hammondmfg.com/1455.htm

www.hammondmfg.com/1455NHD.htm

01256 812812

sales@hammond-electronics.co.uk



ETI BUNDLE (1) Teach-In 3, 4, & 5 All on CDROM ONLY £18.95

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.



ELECTRONICS TEACH-IN 5 CDROM JUMP START

15 design and build circuit projects dedicated to newcomers or those following courses in school and colleges. The projects are: Moisture Detector, Quiz Machine, Battery Voltage Checker, Solar-Powered Charger, Versatile Theft Alarm, Spooky Circuits, Frost Alarm, Mini Christmas Lights, iPod Speaker, Logic Probe, DC Motor Controller, Egg Timer, Signal Injector Probe, Simple Radio Receiver, Temperature Alarm.

PLUS:

PIC' N MIX – starting out with PIC Microcontrollers and PRACTICALLY SPEAKING – the techniques of project construction.

The CD-ROM also contains the complete Teach-In 2 book providing a practical introduction to PIC Microprocessors plus MikroElektronika, Microchip and L-Tek PoScope software.



ELECTRONICS TEACH-IN 4 CD-ROM A BROAD-BASED INTRODUCTION TO ELECTRONICS.

The Teach-In 4 CD-ROM covers three of the most important electronics units that are currently studied in many schools and colleges. These include, Edexcel BTEC level 2 awards and the electronics units of the Diploma in Engineering, Level 2.

The CD-ROM also contains the full Modern Electronics Manual, worth £29.95. The Manual contains over 800 pages of electronics theory, projects, data, assembly instructions and web links.

A package of exceptional value that will appeal to all those interested in learning about electronics or brushing up on their theory, be they hobbyists, students or professionals.



Three Teach-ins for the great price of £18.95

PLUS you also get the contents of the free CDROM from each issue...

... so that's another TWO Teach-Ins and The Full Modern Electronics Manual!

What a Bargain!!

ETI BUNDLE (2) Teach-In 6, 7, & 8 All on CDROM ONLY £18.95

ELECTRONICS TEACH-IN 6 – CDROM A COMPREHENSIVE GUIDE TO RASPBERRY PI Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.



ELECTRONICS TEACH-IN 7 – CDROM DISCRETE LINEAR CIRCUIT DESIGN Mike & Richard Tooley

Teach-In 7 is a complete introduction to the design of analogue electronic circuits. Ideal for everyone interested in electronics as a hobby and for those studying technology at schools and colleges. The CDROM also contains all the circuit software for the course, plus demo CAD software for use with the Teach-In series.

Discrete Linear Circuit Design* Understand linear circuit design* Learn with 'TINA' – modern CAD software* Design simple, but elegant circuits* Five projects to build: Pre-amp, Headphone Amp, Tone Control, VU-meter, High Performance Audio Power Amp. PLUS Audio Out – an analogue expert's take on specialist circuits; *Practically Speaking* – the techniques of project building

ELECTRONICS TEACH-IN 8 – CDROM INTRODUCING THE ARDUINO Mike & Richard Tooley

Hardware – learn about components and circuits; Programming – powerful integrated development system; Microcontrollers – understand control operations; Communications – connect to PCs and other Arduinos

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICKit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICKit 3 User Guide. Also included is Lab-Nation Smartscope software.



ORDER YOUR BUNDLE TODAY JUST CALL 01202 880299
OR VISIT www.epemag.com

When will they learn?

Techno Talk

Mark Nelson

We're back in rant mode this month, with lax computer security as our topic. What's more, you're the loser if organisations you deal with do not handle your personal data with care or if you use smart devices at home.

The expression 'due diligence' is long established in legal and associated circles. It covers all reasonable steps that a person or organisation running a business is expected to undertake to avoid disadvantaging other persons or their property. Normally, there are significant penalties for those who do not undertake due diligence – either by failing to take proper care, by ignorance, by recklessness or a combination of these shortcomings.

Unfortunately, we see or hear far too many examples of failures of due diligence in the media. Frequently, these occur when computer systems 'fall over'; think of mobile phone data services going off the air, online banking services and 'magic money machines' shutting down for several days, or 'household name' companies that confess that computer hackers have stolen their customers' email addresses and bank details. Even scarier are the exploits that you don't hear about, when major organisations are able to hush up incidents such as an attack on public utility infrastructure in which the safety of many thousands of citizens was threatened.

Corporate incompetence

You might be prepared to excuse one-man businesses that get out of their depth, but when it's major corporate organisations that commit these blunders (and whose senior management trouser annual 'remuneration' packages that equal your lifetime earnings), it does make you wonder. These people make crass blunders that blindingly simple measures would have avoided. (I wouldn't even pay them in chocolate money.)

An obvious means of protecting databases and other critical infrastructure against unwelcome attention is not to connect them to the public Internet. That way, 500 million Marriot Hotels customers worldwide would not have had their personal data stolen last November, nor could the £42m hack attack on the TalkTalk website have taken place two years previously. Databases need to be accessible to employees, but over virtual or physical private networks (intranets)

that have no interconnection with the outside world. That's what Her Majesty's Government does, which operates a two PCs-per-desk policy at many locations. Officials use the secure PC for viewing all sensitive material and a 'dirty' machine for accessing the Internet.

Another notorious example of reckless corporate negligence involves Building Management Systems (BMS), which are the means by which the all heating, lighting, ventilation, fire alarm and security systems are controlled and monitored, either for a single building or an entire shopping centre. All of these vital aspects of the built environment can be controlled from a PC, so quite correctly, the suppliers of these systems instruct users not to connect them to the public Internet. You can imagine the havoc that malcontents could cause if they locked all the exit doors of a major shopping mall, disabled the fire alarms, switched off electric lighting and cranked up the temperature inside. But do users heed the warnings not to connect BMS functionality to the Internet? Sadly, they don't, and even though you'd think that an organisation as canny as Google would know better, researchers found that the BMS in its Australian office was connected to the Internet, enabling them to access this successfully. Countless more wide-open BMS installations have been discovered since then.

The enemy within

I have touched on the Internet of Things (IoT) more than once in this column; warning that many IoT gizmos that you install at home or at work communicate in a way that leaves you vulnerable to identity theft and things far worse. Most IoT devices have no anti-virus protection, making them susceptible to malicious firmware updates. These pigeons are coming home to roost.

Last December, Nicole Eagan, CEO of cyber security firm Darktrace, warned that hackers are becoming more sophisticated. 'We have seen attacks on Internet-connected coffee machines [and] through garage door systems. There is

endless creativity to get in the network,' she said. Trustwave, a data security company with three million clients in 86 countries published a report last year stating that 61% of the 137 midsize and large organisations it surveyed had already experienced an IoT security incident. How certain are you about the security of IoT devices that you have installed?

It's a rip-out

The concern that telecommunications network infrastructure made by the Chinese companies Huawei and ZTE could be a security risk may be news to the public at large but it has been discussed in government circles since at least 2007, when the US NSA (National Security Agency) reportedly launched an operation code-named 'Shotgiant', aimed at uncovering possible ties between Huawei and the Chinese military. Last year, the UK's National Cyber Security Centre advised telecoms operators that state-owned ZTE presents a 'risk to UK national security that could not be mitigated effectively or practicably'. The assumption is that Chinese equipment may be compromised by an ability to spy on our voice and data communications, and it is reported widely that the UK government has banned the use of Huawei kit for any 'secure' functions.

However, although BT was alerted of this informally five years ago, the company was then satisfied with the assurances given by Huawei. Belatedly, BT is now removing Huawei equipment from key areas of its 3G and 4G mobile networks, although with no plans to remove it from many other parts of the system. Huawei equipment will not be used in BT's new 5G network, in line with the US, Australia and New Zealand, whose governments (which, along with Canada, make up the Anglophone intelligence alliance – https://en.wikipedia.org/wiki/Five_Eyes). Last July, a British government report into Huawei's broadband and mobile infrastructure equipment concluded that Huawei had provided 'only limited assurance' that its kit posed no threat to national security. Surely, GCHQ must know for certain...

Net Work

Alan Winstanley

Alan Winstanley peers through cracks in the paperless revolution, connects with Google Home Mini and looks forward to the (re)launch of *Practical Electronics*.

Recently, I logged in to check my car breakdown policy, which was set up 'electronically' a year ago, only to find my so-called 'paperwork' had expired and had been deleted from my account. That left me with no idea of the policy's cost, scope or renewal date unless I called them to find out. So much for going paperless! Last month, I mused over the benefits of the paperless revolution, the trend that is seeing more companies favouring electronic billing and correspondence instead of flinging confetti-like clouds of paper at their customers. Paperless systems have a built-in 'gotcha' that can store up all manner of problems for the future. Solicitors or relatives handling probate, or consumers or prospective tenants needing to show a recent 'proper' utility bill for ID purposes, for instance, may find important financial data locked away beyond their reach at a critical time. Or you might want simply to check an account's history, only to find the data is no longer available online.

Are customers being foolhardy in trusting paperless systems? Many Internet users will scan and archive documents onto the cloud (using Microsoft OneDrive, Dropbox or Google Drive, for example), but many still want a hard copy for reference or audit purposes, or they don't have the interest or resources to access Internet-based communications anyway. In anticipation of an unforeseen panic, it's often wise to make a hard copy of key documents, certificates or policies for future reference. If you seldom do any home printing, a cheap £50 mono laser printer is likely to be a better bet than a costly and temperamental inkjet, or a copy shop or library might be able to help.

Hard copy? Hard luck!

Some 20 years ago the author's phone bill included myriad 0845 phone calls for dial-up Internet access and a typical quarter's itemised bill literally ran into 30 pages at a time, something that was clearly not sustainable. BT, Britain's main telecoms provider, has

recently decided to charge customers an extra £3 (\$4) per quarter for every paper bill delivered, the only way to avoid this surcharge being to access accounts via the web instead. BT is only doing what many other providers already do anyway, but their web-based systems seem to change with the wind – a useful online Address Book feature was recently discontinued, but tariffs and invoices remain as complex as ever. I defy anybody to check and digest their BT bills without printing off a hard copy. Surcharges for paper billing are also seen in the broadband and energy sectors, with some utility providers such as EDF reserving the best deals for those who want to deal exclusively online. Once again, it's those for whom the Internet is beyond reach that are losing out, and the paperless revolution begs the question of how such people will be expected to manage their affairs in the future.

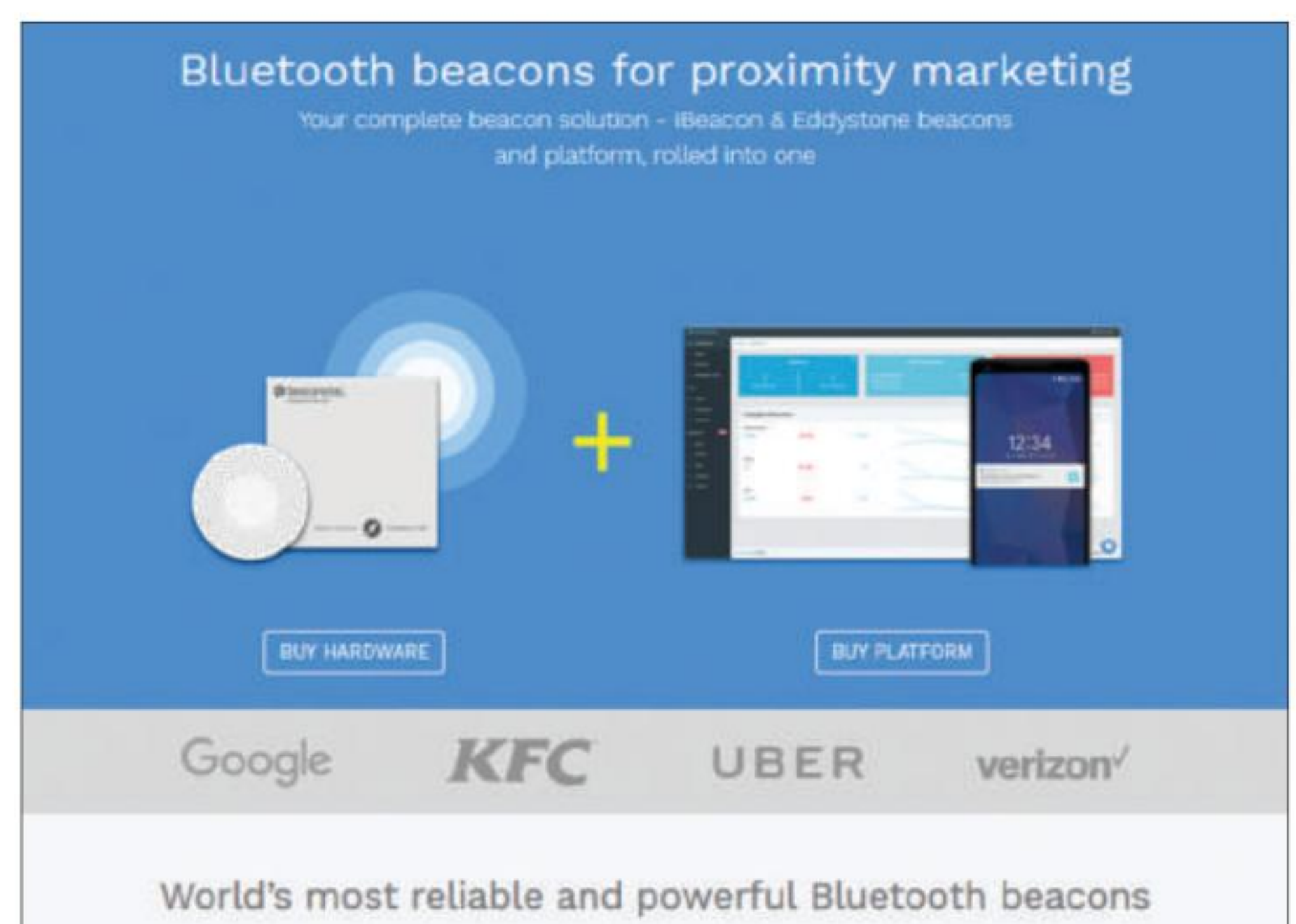
Beacons of hope

Consumers increasingly use their mobile phones to make in-store payments with a simple 'tap' on a card-processing terminal. Even the till receipt remains 'paperless', as buyers, wedded to mobile technology, now waive them in favour of checking transactions on their phone screen some time later, such is their faith in the reliability of modern EPoS systems. Asking for a printed receipt in a convenience store is likely to bring things crashing to a halt, with much tutting and eye-rolling from a line of folks behind you! If you're in the market for a new smartphone, double-check that it has NFC (near-field communication) to enable contactless payments to be made this way. Some stores, such as Halfords or Dunelm, offer to email a store

receipt to you, which is handy. Business users who work on the go are also benefitting from going paperless, thanks to cloud-based accounting systems like Quickbooks that enable purchase invoices and bills to be photographed and uploaded over the net instead of getting lost in the van.

Smartphone users increasingly leave Bluetooth switched on full time. With this in mind, the marketing industry is utilising Bluetooth low-energy (BLE) transmitter 'beacons' to steer consumers (literally, sometimes) towards resources (eg helping travellers use augmented reality (AR) to navigate around an airport terminal – GPS can't work indoors) or to push sales messages at them using a billboard, based purely on their location – a system called 'proximity marketing'. Beacons of various form factors can be hidden discretely around a site, with broadcast ranges from 10m to 300m. London's Gatwick airport boasts that it was the first to use 2,000 such BLE beacons at an air terminal to help travellers find their way around.

Google offers its Eddystone (or Google Beacon) proximity marketing platform and, as you would expect, Google Analytics is heavily utilised by marketers to gauge customer response and effectiveness to ad campaigns in terms of footfall and sales. Apple has its own iBeacon platform.



Bluetooth beacons for proximity marketing

Your complete beacon solution - iBeacon & Eddystone beacons and platform, rolled into one

BUY HARDWARE BUY PLATFORM

Google KFC UBER verizon

World's most reliable and powerful Bluetooth beacons

Beaconstac, a source of proximity marketing beacons and hardware.



The Lenovo Smart Display has 8-inch or 10-inch screens, and built-in Google Assistant.

Virtually anybody can buy into proximity marketing for themselves, including estate agents (realtors), gymnasiums, museums, restaurants and many more, with kits of Bluetooth beacons and SDKs (software development kits) available off the shelf from specialists such as Beaconstac. Next time you're struggling at an airport or sprawling shopping mall, there could be some benign reasons to turn on your phone's Bluetooth.

At home with Google

It's sometimes easy to take pot-shots at the world's largest search engine and ad-monger but, privacy concerns aside, a number of Google's 'free' services have now become almost indispensable in everyday life, including Google Mail, Maps and Street View. The latter even lets you wind the clock back to see a landscape changing as the years go by.

In Britain, the Christmas retail trade was generally muted and some retailers held panic fire sales to drum up some desperately needed trade. Hence, I succumbed to an irresistible offer on the Google Home Mini, priced at just £29 (\$37), and one of these mesh-covered smart speakers is now perched here on my desk. As a general fountain of knowledge, spellchecker, dictionary or

calculator, in my view the Google Assistant reigns supreme and the pod's omni-directional voice recognition skills are sometimes quite astonishing. Google's translation abilities are remarkable too, with Google Assistant usually interpreting my dialect to translate words or sentences seamlessly into foreign languages. A slide switch mutes the microphone and, cleverly, the volume can be set by speaking or tapping the left or right hand edge of the device.

It can be linked to popular subscription music services – but of course broadband and Wi-Fi are required for these cloud-based services, and the Google Home app needs to be installed on an Android or iPhone, for configuring and 'training' with your voice. Overall, performance is impressive and the gadget is proving rewarding to use, which more than compensates for the need to burble 'Hey Google...' before every command.

Other products in the line-up include Google Home Hub, which has a 7-inch LCD screen, is YouTube-friendly and for privacy does *not* have a camera, unlike Amazon's Echo Show, but it can work with Nest smart devices, including thermostats and video doorbells (view caller only). A compact

Google Home Hub is seriously worth considering for a kitchen or bedside.

If you want a larger display, China's Lenovo offers the Lenovo Smart Display, a colour screen with Google Assistant built into a stylish free-standing wedge-shaped unit. Its camera permits video calling and a physical camera shutter/mute button ensures privacy;

both 8-inch and 10-inch LCD models are available. Such is the febrile alertness of Google Assistant that the Lenovo YouTube demo (see: <http://bit.ly/epe-lenovo>) triggered a response from my own Google Home Mini at the mention of 'Hey Google – Good Morning!'. Mine replied, Hi, Alan! The news and weather followed until I finally gagged it.

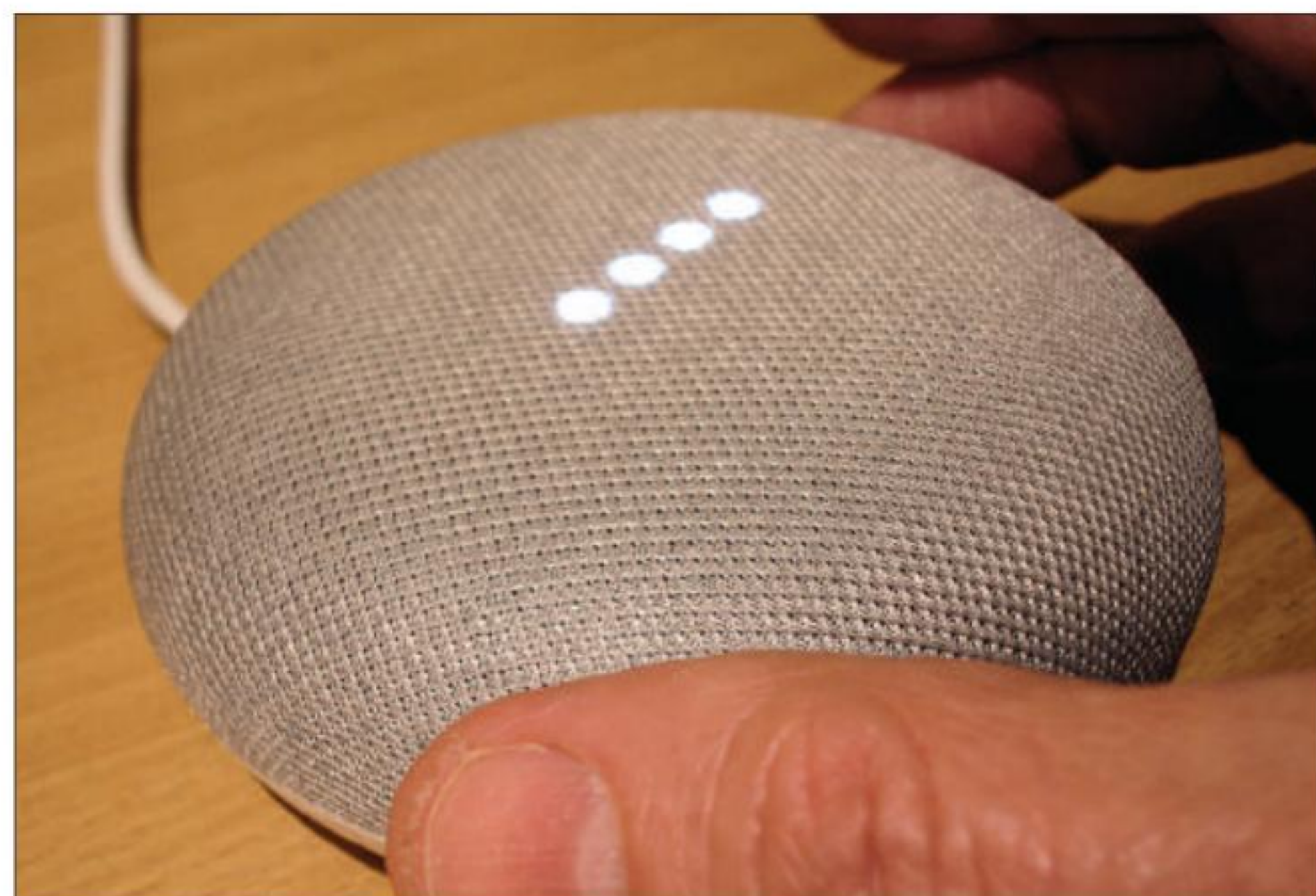
Other devices that incorporate Google Assistant include the Zolo Mojo Wi-Fi/Bluetooth Home Speaker, but be sure to check out online reviews. If, however, you are a frequent Amazon shopper then their Echo smart devices will prove a more useful family-friendly solution, and you might want to install Amazon Assistant as a web browser extension too, to pop up with latest prices of any merchandise you are currently browsing. All devices mentioned are also capable of controlling a smart home, and thousands of IoT products are now available in this fast-growing sector that interface with smart lights, thermostats, cameras, baby monitors, security systems and more.

A very important week

An American correspondent recently messaged me to ask, what does 'Brexit' mean? I explained that this innocuous-sounding portmanteau stood for Britain Exiting the European Union, the most seismic geopolitical event to hit the UK in nearly 50 years. A new lexicon of jargon such as 'Remainers', 'Brexiters' and terms such as 'Irish Backstop' and even 'Remoaners' now populates our dialect as Britain pores over the consequences, both good and bad, of the forthcoming Brexit deadline. The date for our diary is 29 March 2019 at 23:00 hours when, in theory anyway, the UK will no longer be an EU member state. Onlookers might want to keep an eye on the *Financial Times* countdown clock at: <http://bit.ly/epe-ftclock> (Incidentally you can give your own events a countdown timer with a unique URL at: <https://howmanydaystill.com>)

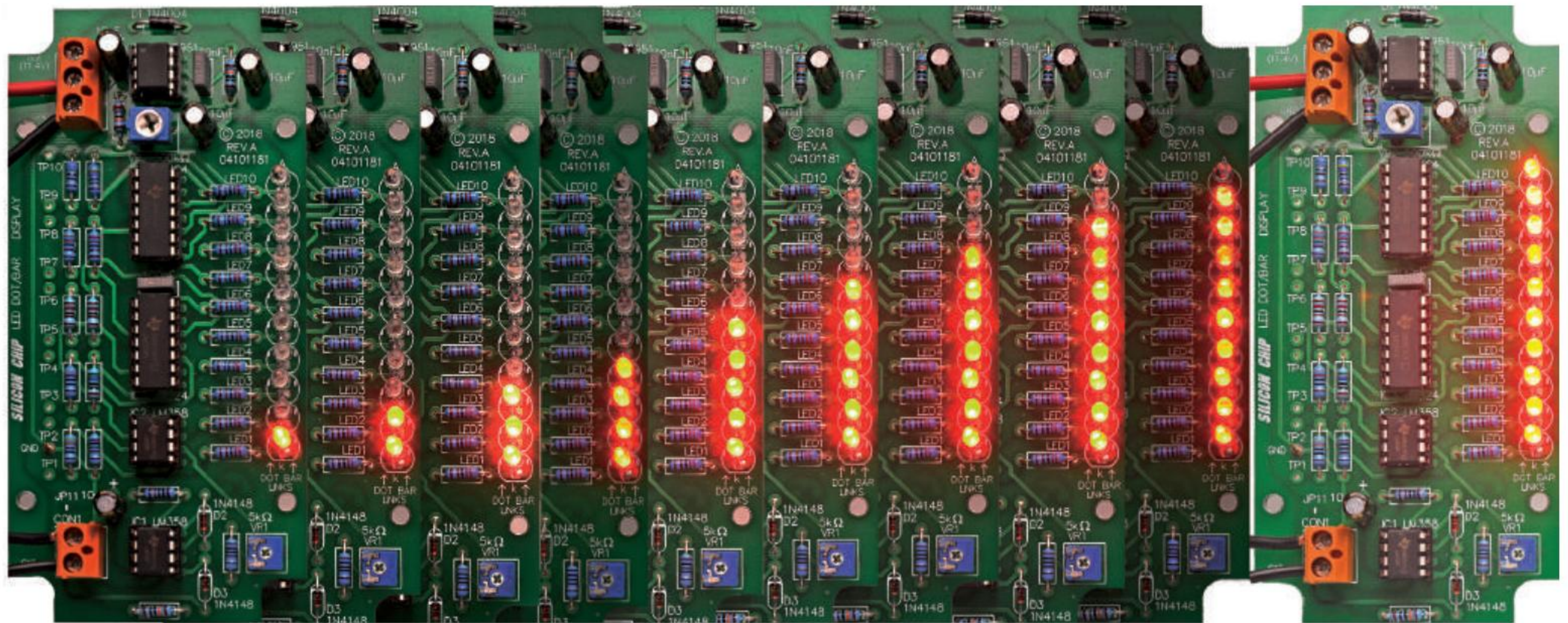
There's more to life than Brexit, and regardless of how it turns out, we'll know what we need to know by the time the other big event of that week happens. Naturally, I'm talking about the May issue of *PE* hitting the newsstands on 4 April! Remember, by then it will be the *second* issue of *P.E.* – so don't forget to look out for our name change and stylish new livery as *EPE* revert to its roots and once again becomes *Practical Electronics*.

The author can be reached at:
alan@epemag.net



Google Home Mini has a touch-activated volume control, or you can use voice commands (Photo: Alan Winstanley).

10-LED Bargraph



Flexible display options By JOHN CLARKE

Want a really flexible bargraph? This *10-LED Bargraph* will fill the bill. It can be configured for dot or bar mode, while for audio signal monitoring, extra circuitry can be added to provide for VU or Peak Program Metering (PPM). It's a worthy replacement for the now-discontinued LM391X series of bargraph chips.

LED bargraph are ubiquitous – you will find these displays in all sorts of electronic equipment.

They can be horizontal, vertical, curved, circular or other shapes. They give an immediate visual indication of operating conditions, whether monitoring voltage levels or physical parameters such as temperature, audio signal level or whatever, and they can be designed to react rapidly or slowly.

While many displays these days are digital read-outs, bargraphs are much better at showing variations in

level, especially if those variations happen quickly.

This *10-LED Bargraph* indicates DC voltage levels in a series of 10 steps, but those DC voltages can correspond to any physical measurement, as noted above. The voltage steps to light each subsequent LED can be equal, meaning that the display is linear, or the steps can be non-linear, for example, a logarithmic display. In that case, each step could amount to say a 3dB increment.

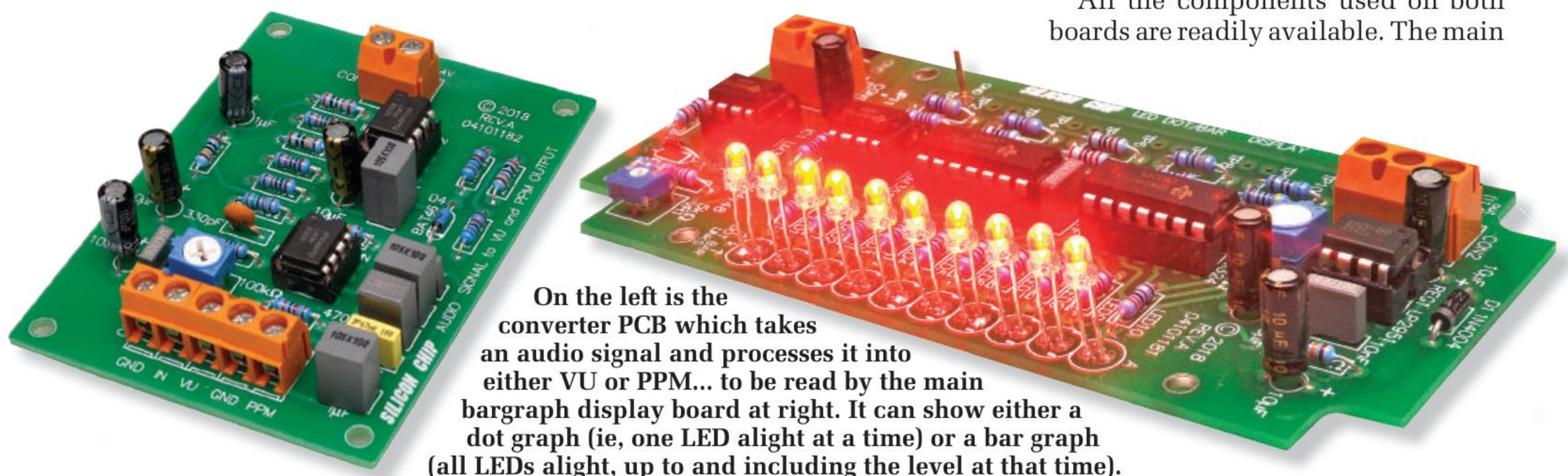
It's easy to build this bargraph with a linear, logarithmic or any other scale

since the steps are determined by a set of resistors, connected in series. We provide examples of the resistors to use for linear, logarithmic or VU (audio level) scales.

Alternatively, you could produce your own custom scale by using a different set of resistors.

This project is presented on two PCBs. One is the *LED Dot/Bar Display* PCB and the other is the optional *Signal Processing* PCB, which is used to convert an AC signal into a suitable DC voltage to drive the bargraph.

All the components used on both boards are readily available. The main



On the left is the converter PCB which takes an audio signal and processes it into either VU or PPM... to be read by the main bargraph display board at right. It can show either a dot graph (ie, one LED alight at a time) or a bar graph (all LEDs alight, up to and including the level at that time).

integrated circuits are: LM358 dual op amps, two LM324 quad op amps and one LP2951 voltage regulator, with most of the remaining components being resistors and capacitors. The LEDs that form the bargraph itself can be surface-mount types that sit directly on the PCB, or standard 3mm LEDs.

The LEDs will light up singly in dot mode or a column of LEDs will light up in bargraph mode. The display mode is selected by bridging pairs of solder pads on the PCB, with nine links (bridges) to solder for each mode. Once you've built the unit, it is configured as either a dot or bar display and this can't easily be changed later.

Why not use an LM3914/5/6?

No doubt some readers are already thinking, 'Why do we need all these comparators when single chip bargraph ICs from National Semiconductor can already do this?'

The National Semiconductor LM3914 (linear) LM3915 (logarithmic) and LM3916 (VU) bargraph ICs certainly can do these jobs and they have been very widely used for many years.

However, the LM3915 has not been manufactured by National Semiconductor for 15 years, and although we are aware that there are still dribs and drabs around from some sources, NS advise not to base any new designs on this chip. So we won't!

Its cousin, the LM3916, was discontinued many years ago and is effectively no longer available. The only one that seems to be readily available in large quantities is the LM3914 – but the problem with this is that it can only display a linear scale.

And while these three bargraph ICs present an easy single-chip solution

for many dot/bar-graph applications, they do have limitations when you want to customise the circuit parameters.

For example, the LM3914 linear bargraph will always have an overlap in the transition from one LED to the next. That means that at least one LED is always illuminated but it does reduce the precision of the display.

In the case of the logarithmic LM3915, the LED step increments are fixed at 3dB, giving a 30dB range. You cannot change the size of the steps to 2dB, or less, for example.

And for both chips working in bargraph mode, all the illuminated LEDs are effectively in parallel and that can cause heat dissipation problems; the chips have limited power handling.

Indeed, for many audio signal bargraph applications, the circuit we present in this article is far more useful. This is particularly the case in audio mixers where multiple LED bargraphs are required, with a resultant high current requirement. In those cases, the LM3914/5/6 series is definitely not ideal.

Yes, our 10-LED bargraph does use more components than the single-chip chip circuits, but all the components are cheap and readily available and you can customise the circuit to suit your particular application, something that is not easy to do with the chip circuits.

Finally, these two boards provide an aid to demonstrate the use of op amps

Features and specifications

- 10 LEDs – you decide which type or colour
- Dot or Bar modes
- DC or AC input voltages
- Linear, Logarithmic, VU or PPM display
- Runs from 12V (100mA maximum)
- Full-scale signal range adjustable from 583mV to 55V
- Uses readily available components
- Suits surface-mount or through-hole LEDs

as comparators, window comparators and driving LEDs, along with signal metering and overall bargraph design.

How it works

The 10-LED Bargraph circuit comprises ten op amps (operational amplifiers) that are used as comparators. Each drives one of the LEDs, switching it on when the input voltage exceeds (or drops below) a set threshold.

To begin, let's consider Fig.1, which shows a single op amp (IC2a) connected as a comparator to drive an LED.

The op amp's inverting input (–) pin 2 is connected to the input signal, while the non-inverting input (+) pin 3 is connected to a voltage divider comprising resistors R1 and R2, connected in series between a reference voltage (V_{ref}) and ground.

Assuming that these resistors are the same value, the junction of R1 and R2 is one half of V_{ref} (ie, $V_{ref}/2$). So pin 3 of IC2a is held at $V_{ref}/2$. Now, if the input signal at pin 2 is lower than $V_{ref}/2$, the output of IC2a will be high. But if the input signal at pin 2 is greater than $V_{ref}/2$, the output of IC2a will be low (close to 0V).

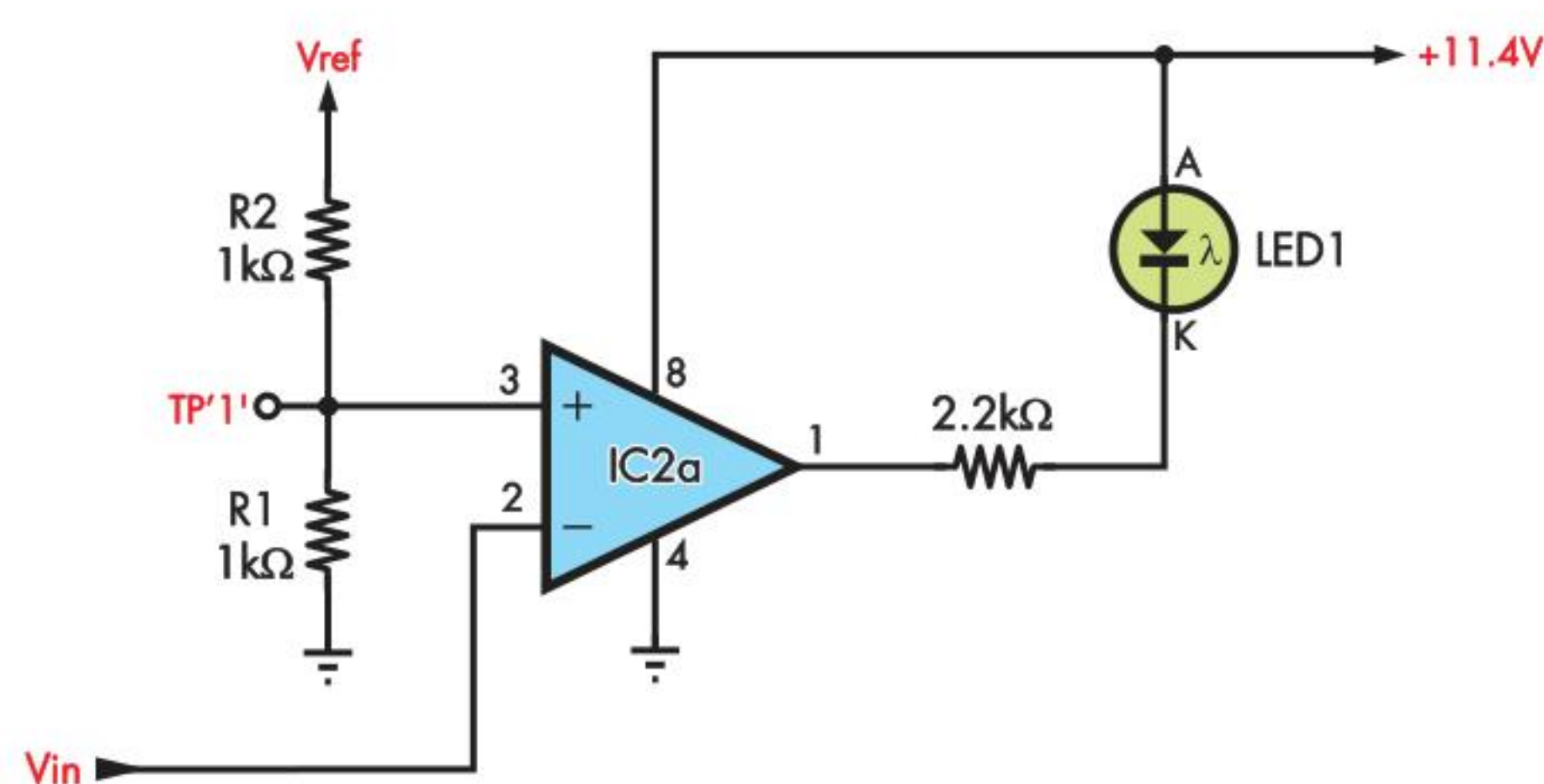
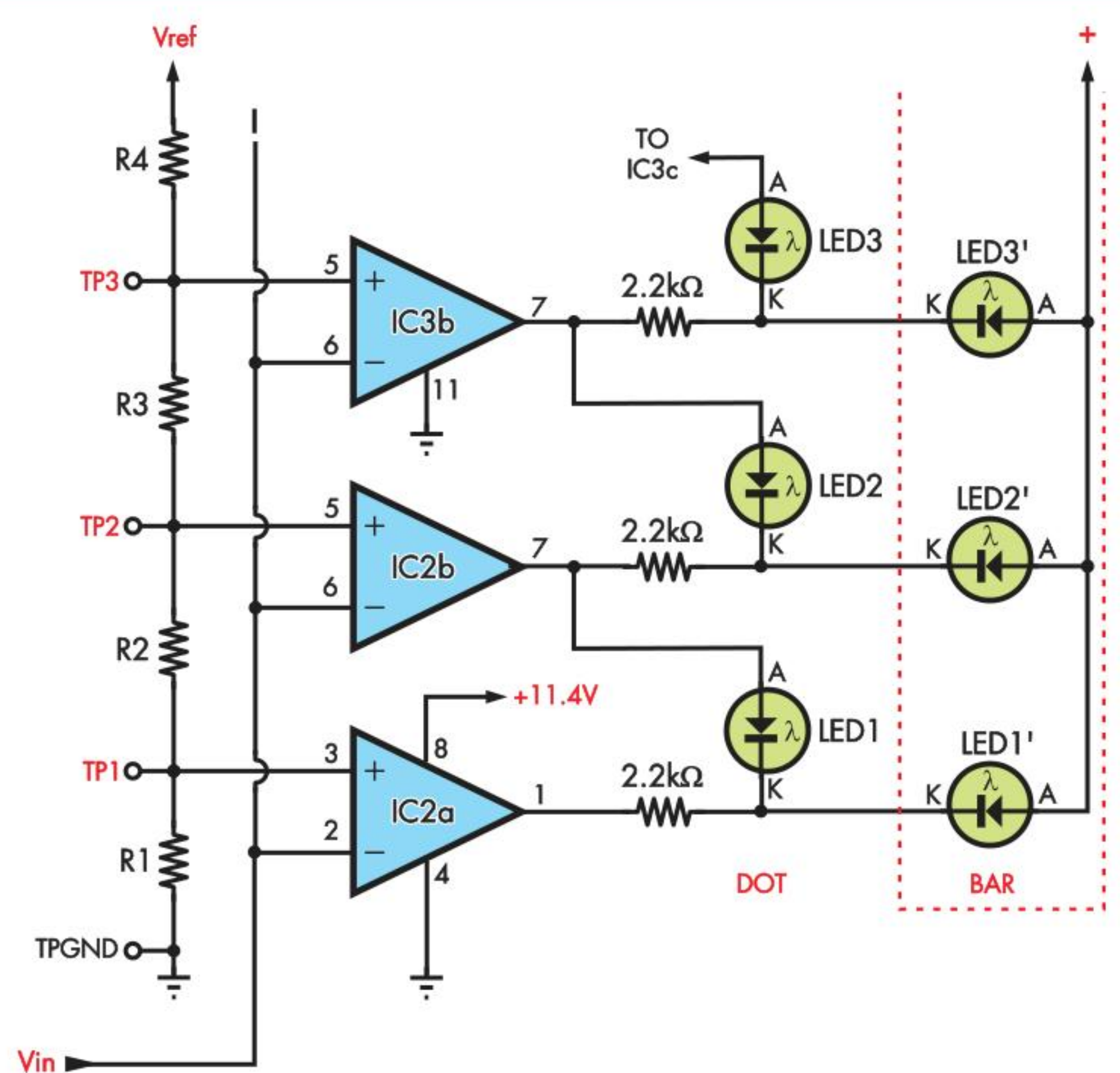


Fig.1 (above): this shows the operation of a comparator. It compares the input signal with a reference at its non-inverting input and turns on the LED if the input is above the reference.

Fig.2 (right): this set-up combines three comparators, each with separate reference voltages at TP1, TP2 and TP3. Each comparator will turn on its respective LED if the input voltage is above its reference voltage. The different LED connections provide for dot or bar modes.



That means that the op amp will pull current through the LED to light it up.

Note that we could use a comparator IC (such as the LM339) to perform this same function, but if we wanted to reverse the action of the comparator, to drive an LED connected between its output and the 0V rail, it would not work since that type of comparator can only 'sink' current rather than 'source' it.

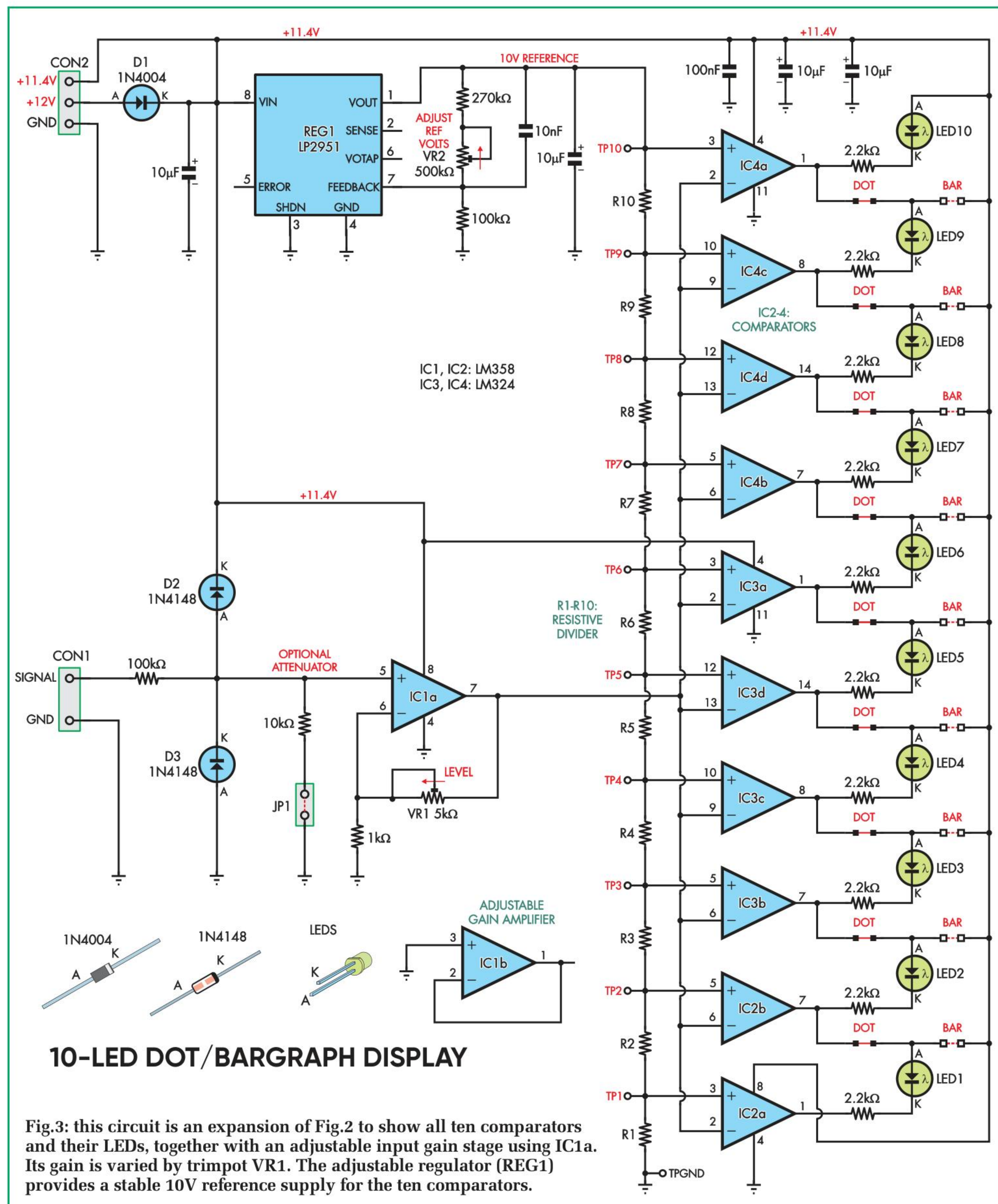
So we use op amps throughout our circuit because their push-pull outputs make them more flexible.

Next, we want to drive more LEDs. For that, we add more 'comparators', or in this case, op amps.

Fig.2 shows a triple comparator set-up, with each comparator driving one LED and with its non-inverting input connected to a resistor higher in the series string. The inverting inputs

are connected together to monitor the same signal (V_{in}).

Remember, that while we will refer to 'comparators' in this article, in each case they will actually be op amps. It's worth noting that op amp and comparator ICs contain almost identical circuitry; the main difference, besides the output configuration, is that op amps are compensated for closed-loop stability, which makes them slower to



react. But for this project, we're dealing with (relatively) slow-changing signals, so that isn't a problem.

(Op amps are normally configured with external negative feedback while comparators normally have positive feedback – hysteresis).

Fig.2 also shows the LED connections for the dot and bar modes. In bar mode, each LED connects between the positive supply and the op amp output via a series 2.2kΩ resistor. This means each LED will light whenever its comparator output is low.

For dot mode, the anode of each LED connects to the next higher op amp output. So an LED will light when the higher op amp output is high and the lower op amp output is low.

For example, with LED1, when V_{in} is higher than the voltage at TP1 but lower than the voltage at TP2, the output of IC2a will go low and current will flow from the output of IC2b, through LED1 and the 2.2kΩ resistor and then into the output of IC2a.

In other words, IC2b is 'sourcing' LED1's current while IC2a is acting as the 'current sink'. As stated above, this would not work with a typical (open-collector output) comparator.

Now, when the voltage at V_{in} goes above the voltage at TP2 but is still lower than at TP3, IC2b's output will go low, switching off LED1, but it will sink current through LED2 which ultimately comes from the output of IC3b.

Therefore, in dot mode, only one LED will light at any given time.

For bargraph mode, the LEDs are reconfigured as shown in Fig.2 (LED1', LED2' ...) and so they will light up whenever the associated comparator output goes low, so if LED2' is lit, LED1' will be lit and if LED3' is lit then LED2' and LED1' will also be lit.

Switching thresholds and dithering LEDs

Having said that, it is possible for two LEDs to be alight (or partly alight) when the input signal is close to one of the voltage thresholds, defined by the reference resistor 'ladder' (ie, at TP1, TP2...).

This is due to the fact that the op amps have inherent noise which can cause them to rapidly switch on and off when the two input voltages are very close together.

This can be prevented by using hysteresis and, as mentioned above, this involves adding positive feedback between the output of each comparator and its non-inverting input.

However, that would require the addition of three resistors to each (op amp) comparator and we have not done that with this 10-LED bargraph circuit since it would mean an additional 30 resistors. That's a lot of hassle to solve a minor problem.

Full circuit description

Now let's have a look at the full circuit of the 10-LED dot/bargraph display in Fig.3. This shows the 10 (op amp) comparators and the 10-resistor ladder network providing the reference voltage for each comparator.

The resistor network is connected to the output of adjustable voltage regulator REG1, an LP2951. This ensures a stable voltage to the resistor string regardless of variations in the input supply voltage. REG1's output voltage is adjusted by trimpot VR2 to a precise 10V DC.

Note that this bargraph circuit by itself is only suitable with a DC input signal; it will not respond to an audio (AC) input signal. In this respect, it is the same as bargraph circuits using

the LM3914/15 series chips. (We will get to the additional circuitry which allows that later.)

The DC input signal is applied to CON1 and voltage is limited by clamping diodes D2 and D3, to a range of 0-11.4V, protecting the circuit from excessive voltages. The input 100kΩ resistor limits the current through D2 and D3 to safe levels.

If the input voltage to be monitored swings by more than 10V, it should be attenuated and that can be done by installing link JP1. That places a 10kΩ resistor in circuit which, in conjunction with the input 100kΩ resistor following CON1, attenuates the signal by a factor of 11.

Op amp IC1a is configured as a non-inverting amplifier with its gain varied by trimpot VR1. Its gain can be set to between unity (one) and six.

Note that op amp IC1b (part of the same dual op amp) is not used in the circuit and it is disabled by having its pins 1 and 2 connected together and pin 3 connected to 0V (GND), so it won't oscillate or otherwise misbehave.

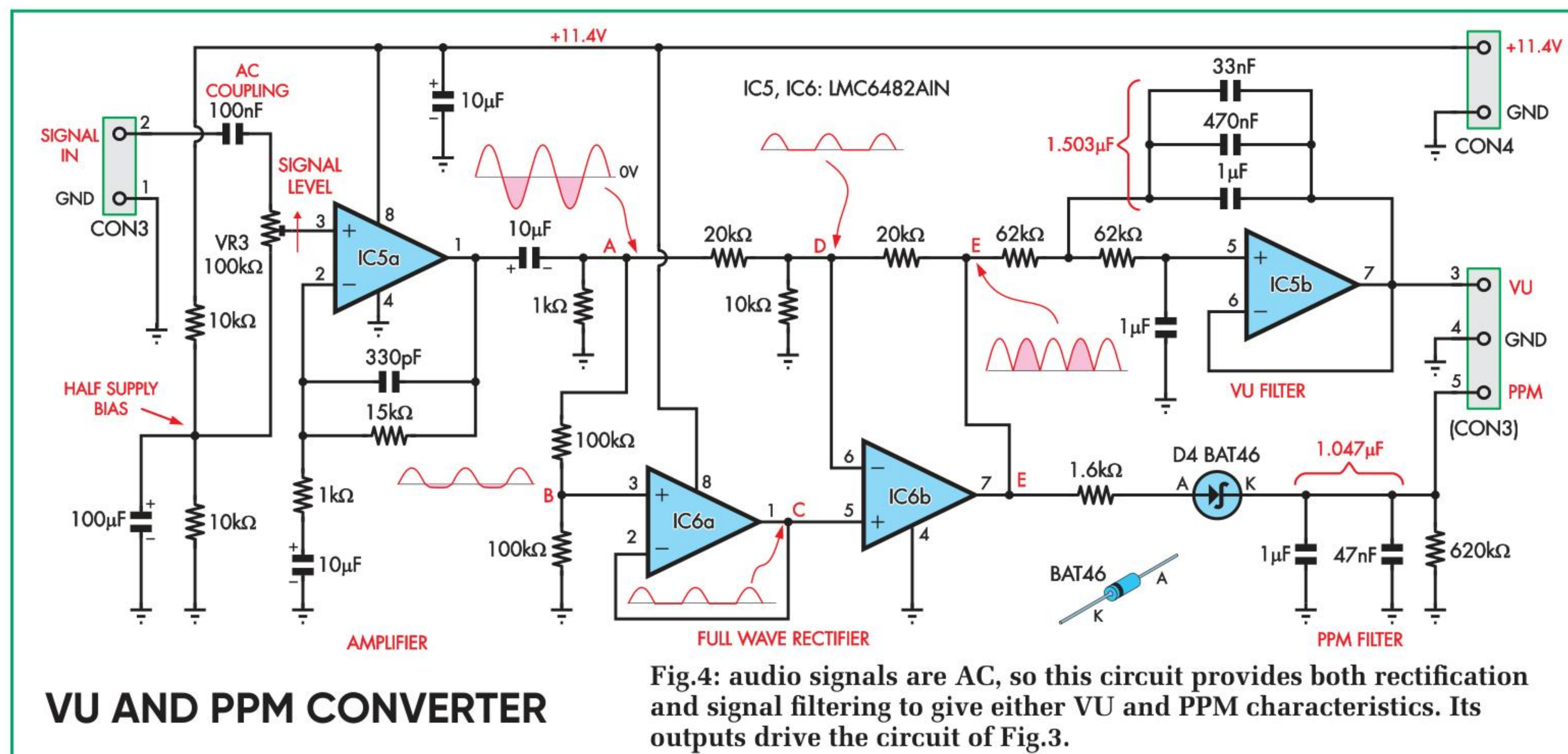
The circuit is set for dot or bar modes by soldering the appropriate set of PCB copper pads at the output of each op amp comparator, ie, either all the 'DOT' pad pairs are joined or all the 'BAR' pad pairs are joined.

The operation is then as described above, only with ten LEDs rather than three.

Handling audio signals

If you connect an audio signal up to CON1, half of it would be clipped by D3 and the other half would cause the bargraph to swing up and down rapidly; not really an ideal situation.

A better solution is to amplify, rectify and filter the audio signal to



produce a DC level corresponding to its peak or average amplitude.

There are many different ways to do this, two of which are known as 'VU' Meter or 'Peak Program Meter' (PPM) displays. Further signal processing is required to achieve these responses.

All these possibilities are covered by the *Signal Processing* circuit shown in Fig.4.

It consists of a non-inverting amplification stage (IC5a), a precision full-wave signal rectifier (IC6a and IC6b) and a VU-response filter stage (IC5b). IC5 and IC6 are LMC6482AIN dual rail-to-rail op amps.

The audio input signal from CON1 is fed via a 100nF capacitor and applied to potentiometer VR3. Instead of being directly grounded, the 'cold' side of VR3 is connected to a voltage divider of two 10kΩ resistors, with the junction bypassed with a 100μF capacitor.

This method of connection allows the incoming signal to swing symmetrically about the half-supply point (around 5.7V; ie, 11.4V÷2).

Op amp IC5a amplifies the attenuated signal by a factor of 16, giving a gain range of 0-16. Gain is reduced for frequencies above 32kHz due to the 330pF capacitor across the 15kΩ negative feedback resistor.

Its low-frequency response rolls off below 16Hz, as set by the 1kΩ resistor and 10μF capacitor between the inverting input (pin 2) and ground (0V).

Precision rectification without diodes

The output signal from IC5a is fed via a 10μF capacitor to the precision full-wave rectifier comprising IC6a and IC6b. Its job is to convert the negative voltage portions of the signal into positive voltages so that we can determine the average signal level (the average of a symmetrical AC waveform is 0V).

This precision rectifier is unusual in that it does not use any diodes and nor does it need a negative supply rail. It works because the op amps are rail-to-rail types. This means that while their inputs and outputs can swing from within a few millivolts below +11.4V (ie, the positive supply rail) to 0V (or actually to -0.3V in the case of the input), if the input signal swings negative, the op amp's output will swing down to 0V but go no further.

So if we apply a sinewave centred about 0V to the input of voltage follower IC6a, its output will precisely follow the input signal for the positive excursion of the signal but the negative excursions will result in a 0V ('clipped') output. This means that the output signal at pin 1 will be a half-wave rectified sinewave.

So that gives us a positive-going signal but only for the positive half of the AC signal. We need the whole thing. This is provided by IC6b and the way it works is very clever.

When the input signal at 'A' is below 0V, the output of IC6a (at 'C') is 0V as described above and thus the non-inverting input pin 5 of IC6b is at 0V; so it is grounded. It now becomes an inverting amplifier with a gain of -1, as determined by the two 20kΩ resistors at pin 6, one from the output at pin 7 and one from the input signal, at 'A'.

The third 10kΩ resistor is irrelevant since with an inverting amplifier, both inputs are at 0V and therefore that resistor will have 0V at both ends, so no current will flow through it. It's effectively out of circuit when the input signal is negative.

So IC6b will invert the negative-going signal at point 'A' to an identical but inverted positive voltage signal at pin 7 ('E').

But when the input signal swings positive, the output of IC6a at 'C' will be identical to the input signal but with half the amplitude, because of the resistive divider at its input (pin 3).

Here's where it gets a bit tricky. Op amps use negative feedback to attempt to keep both their input pins at the same voltage. We have half the input voltage at pin 5 of IC6b, so we would expect to also see half the input voltage at pin 6.

The question then is what output voltage from IC6b is required to provide this. We have the full input signal at 'A', which then flows through a 20kΩ resistor to 'D'.

What do 'VU' and 'PPM' stand for – and what do they measure?

Just about everyone would have seen (or at least seen a picture of) a meter on an amplifier or tape recorder labelled 'VU' with a scale running from -20 to +3, so it's a reasonable assumption that it is displaying 'VUs', whatever they are! The VU – which, incidentally, stands for 'Volume Unit' – is arguably the most misunderstood 'measurement' (along with the decibel) in the whole of electronics. Peak Program Meter, or PPM for short, probably runs them a close second, and we'll get to that in a moment.

What is a Volume Unit?

Even though the VU meters found in a lot of consumer equipment are not particularly accurate (many are there more for show than anything), the Volume Unit is actually an accurately defined quantity. It was first developed in the US in 1939 by Bell Labs, along with broadcasters CBS and NBC, to show the 'perceived loudness' of an audio signal. It became a US (and later international) standard in 1942.

The standard states that a reading of 0VU equals 1.228V RMS at 1000Hz across a 600Ω resistance. Confused? Don't

be: just remember that the VU meter is normally used to provide a quick visual guide, not give a definitive measurement.

Mechanical VU meters are slow to react to changes in level – deliberately so. This is partly due to the inertia of the meter itself (or ballistics) but also due to the circuitry around it; in effect, the VU meter integrates the signal, presenting an average level rather than an instantaneous (or peak) level.

The whole point of a VU meter is to show a level which the circuit as a whole can handle without overloading (causing distortion). That's normally a level of 0 (zero) VU (on many VU meters this will also be shown as 100%).



Above that (usually marked by a red zone on mechanical VU meters) you run the risk of overload – especially, for example, when you're recording to an analogue tape recorder. That's why you adjust the level so that the reading seldom, if ever, goes much over 0VU.

Incidentally, VU meters and signals with lots of sharp transients (eg, drums) do not work well together – so much so that the VU meter, especially the mechanical variety, has fallen out of favour in recent years. This is precisely why we are presenting our highly flexible LED version!

The Peak Program Meter

This is a variation on the VU meter which shows, as its name suggests, the 'peak' (or maximum) signal level. Again, this is designed to stop you over-driving a circuit or a recorder.

The PPM is often just a single LED which flashes on maximum level. If you set a level where the LED is mostly on, you will undoubtedly get a distorted signal.

Sometimes a VU meter will also incorporate an LED (as seen in the photo at left) to give this indication.

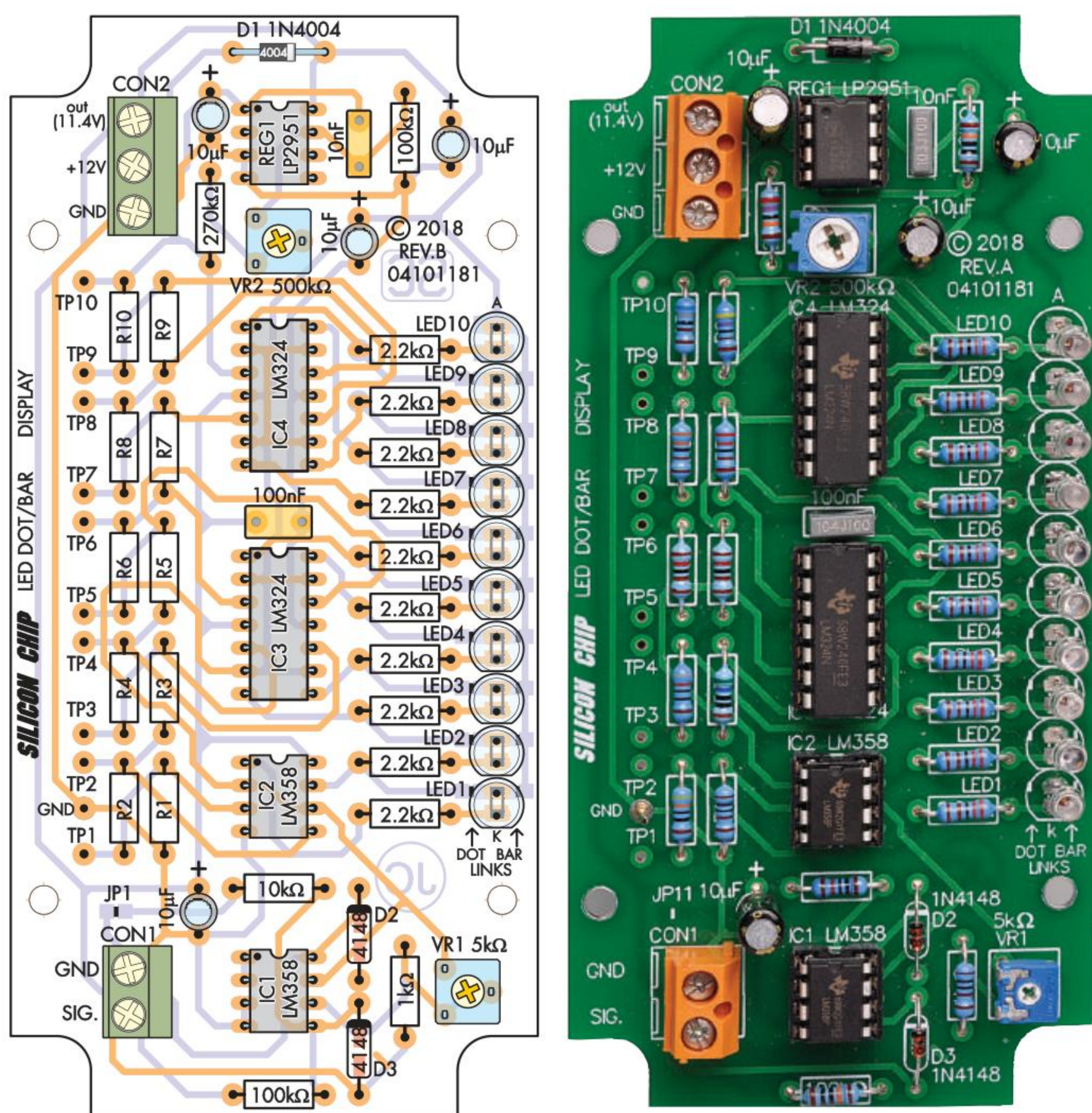


Fig.5: here's how to assemble the LED display PCB, which is shown here with a matching same-size photo. Make sure you connect the bar or dot pads (not both) on the underside of the PCB.

If we assume that the output of IC6b is identical to the input signal (ie, the signal at 'E' is equal to the signal at 'A') then we can consider the two 20kΩ resistors to be in parallel, meaning the current is effectively flowing through a single 10kΩ resistor.

This virtual resistor forms a voltage divider with the 10kΩ resistor from 'D' to ground, reducing the signal amplitude by half.

This matches the signal that's already present at 'C', hence, this is the condition which will keep both op amp input voltages equal.

And that means that for positive voltages at 'A', the output at 'E' must be an identical signal.

Since we've just demonstrated that the output at 'E' is identical to the input at 'A' for positive voltages and an exact, inverted version for negative voltages, that means that the signal at 'E' must be a rectified version of the signal at 'A'.

We have attempted to illustrate this rectification process with the waveforms at the various circuit points. So there is an sinewave shown at point A and resulting half-wave rectified signal with positive half cycles at points B, C and D. Note the periods for which points B and C and therefore pin 5 are held at 0V.

We have shaded the negative-going portions of the signal at point 'A'. These portions are effectively ignored by IC6a because it cannot respond to them.

But note the complete rectified waveform at point E. See that it includes the shaded portions of the signal which have been inverted and amplified by IC6b.

Filtering and processing

We now need to filter that rectified signal to recover a DC voltage that's proportional to either the peak of the incoming signal or the average, or some combination of the two with differing time constants (ie, VU or PPM).

VU metering was originally provided by a mechanical meter with particular physical characteristics which determined its response to signals.

It is not ideal for indicating transient signals that can cause amplifier clipping or excessive recording levels. However, the display is good for a general guide to signal levels.

The electronic VU filter built around op amp IC5b simulates the ballistics of a mechanical VU meter, which is relatively slow in responding to level changes.

It is specified that upon a step change in the input level, it must

reach 99% deflection in 300ms with a 1-1.5% maximum overshoot. This requires a second-order low-pass filter with a high-frequency roll-off at 2.1Hz and with a Q of 0.62.

IC5b is configured as a Sallen-Key filter with the above dynamic characteristics to produce the VU output at pin 3 of CON3.

If you're recording audio and are concerned about clipping (ie, the recording level exceeding the capability of the recorder to cleanly reproduce it), you are better off using a Peak Program Meter (PPM) indicator.

A PPM meter is built using a filter which ignores very short transients but otherwise has a fast attack and slow decay, so you can better see the peak level.

Its response should be 1dB down from the peak level for 10ms tone bursts and 4dB down for 3ms tone bursts.

These requirements are met by a filter with an attack time constant of 1.7ms and a 650ms decay rate.

Here we use a schottky diode (D4) to charge the 1.047μF capacitance (ie, 1μF and 47nF in parallel) via a 1.6kΩ resistor, which sets the attack time constant. The decay rate is set by the combination of the above capacitance and the parallel 620kΩ discharge resistor.

Construction

The 10-LED Bargraph is constructed on a PCB coded 04101181 and measuring 58 × 122mm. It fits into an optional UB3 plastic utility box measuring 130 × 68 × 44mm. Follow the overlay diagram of Fig.5 to see how each component is soldered to the PCB.

Before construction, decide whether you want a dot or bar display and whether you need a linear, log or VU scale. Use Table 1 to select the values of resistors R1-R10, according to your scale requirement.

Fit the resistors first. You can check the colour code for each resistor value by reading the resistor colour code, but we recommend that you also check each resistor value with a digital multimeter before soldering.

Resistors are not polarised, but it is a good idea to install them so that their colour codes all run in the same direction. This makes it so much easier to check their values later on.

Dot or Bar mode selection

If you want a dot display (ie, only one LED lit at a time), each pair of pads labelled 'DOT' will need to be bridged with solder. There are nine such pairs. The dot links are on the underside of the PCB, between the end of the 2.2kΩ resistor and the LED anode.

Parts list for 10-LED Bar/Dot Graph

- 1 double-sided PCB, coded 04101181, 58 × 122mm
- 1 UB3 plastic utility box 130 × 68 × 44mm (optional)
- 2 14-pin DIL IC sockets
- 3 8-pin DIL IC sockets
- 1 2-way PCB-mount screw terminal (5/5.08mm spacing) (CON1)
- 1 3-way PCB-mount screw terminal (5/5.08mm spacing) (CON2)
- 1 PC stake
- 1 5kΩ mini horizontal trimpot (VR1)
- 1 500kΩ mini horizontal trimpot (VR2)
- 1 10kΩ 16mm linear potentiometer (for testing purposes)

Semiconductors

- 2 LM358 dual op amps (IC1,IC2)
- 2 LM324 quad op amps (IC3,IC4)
- 1 LP2951 adjustable regulator (REG1)
- 1 1N4004 1A diode (D1)
- 2 1N4148 small-signal diodes (D2,D3)
- 10 3mm or SMD 1206 LEDs (LED1-LED10)

Capacitors

- 4 10μF 16V PC electrolytic
- 1 100nF 63V/100V MKT polyester
- 1 10nF 63V/100V MKT polyester

Resistors (all 0.25W, 1%)

- 1 270kΩ 2 100kΩ 1 10kΩ
- 10 2.2kΩ 1 1kΩ

For linear scale, add:

- 10 1kΩ (R1-R10)

For log scale, add:

- 1 6.8kΩ 1 4.7kΩ 1 3.3kΩ 1 2.2kΩ
- 1 1.6kΩ 1 1.2kΩ 1 820Ω 1 560Ω
- 1 430Ω 1 1kΩ

For VU scale, add:

- 1 1.1kΩ 2 1kΩ 2 820Ω 1 750Ω
- 1 1.3kΩ 1 910Ω 1 1.5kΩ 1 680Ω

Parts for Signal Processing board

- 1 double-sided PCB, coded 04101182, 58 × 81mm
- 2 14-pin DIL IC sockets
- 2 2-way PCB-mount screw terminals (5/5.08mm spacing) (CON3,CON4)
- 1 3-way PCB-mount screw terminal (5/5.08mm spacing) (CON3)
- 1 100kΩ mini horizontal trimpot (VR3)

Semiconductors

- 2 LMC6482AIN CMOS dual op amps (IC5,IC6)
- 1 BAT46 diode (D4)

Capacitors

- 1 100μF 16V PC electrolytic
- 3 10μF 16V PC electrolytic
- 3 1μF 63V/100V MKT polyester
- 1 470nF 63V/100V MKT polyester
- 1 100nF 63V/100V MKT polyester
- 1 47nF 63V/100V MKT polyester
- 1 33nF 63V/100V MKT polyester
- 1 330pF ceramic

Resistors (all 0.25W, 1%)

- 1 620kΩ 2 100kΩ 2 62kΩ 2 20kΩ
- 1 15kΩ 3 10kΩ 1 1.6kΩ 2 1kΩ

as shown on the PCB overlay, with the longer lead to the + side and the negative stripe on the opposite side.

Electrolytic capacitors will have their value and voltage rating printed on them while MKTs are marked with a code indicating their capacitance ('103' 10nF, '333' 33nF, '473' 47nF, '104' 100nF, '474' 470nF, '105' 1μF).

Now install diodes D1, D2 and D3; D1 is a 1N4004 (1A) type while D2 and D3 are 1N4148s (signal diodes).

You can then solder a single PC stake at the GND terminal position. This allows you to use an alligator clip lead to connect the negative probe of a meter to the circuit, while the positive lead with a standard needle probe can be used to contact test points TP1-TP10.

IC sockets for IC1-IC4 and REG1 should then be installed with the notched end towards pin 1. (Before soldering, check that all the pins have gone through the holes in the PCB and that none are bent under the socket.)

Terminal blocks CON1 and CON2 must be fitted with the wire entry holes to the nearest edge of the PCB.

Trimpots VR1 and VR2 can then be installed. VR1 is a 5kΩ trimpot that may be marked as '503' instead of '5k'. Similarly, VR2 may be marked as '504' instead of '500k'. Don't get them mixed up.

Now for the LEDs; if using surface-mount LEDs, these are soldered in place on the top of the PCB with the anode of each toward the top of the PCB.

Use a multimeter set to diode test to check which is the anode and the cathode on each LED. The LED will glow when the red positive lead is on the anode (A) and the black negative lead on the cathode (k).

If you're using leaded LEDs, then the longer lead is the anode. Install these at an equal height above the PCB, which is most easily done using a spacer between the legs to set the height during soldering.

Now straighten the IC leads and insert them into their IC sockets, making sure that REG1 is not mixed up with IC1/IC2 and that each is oriented correctly – ie, pin 1 notch/dot lined up with the socket notches, as shown.

Signal processing board assembly

You only need to build this board if you are feeding an audio signal into the 10-LED Bargraph. The PCB is coded 04101182 and measures 58 × 81mm. It can be stacked below the 10-LED Bargraph on 15mm standoffs if required. The overlay diagram is shown in Fig.6. As before, solder the resistors first, then the sole diode (D4), then the capacitors.

Note that along with the MKT and electrolytic capacitors, this board also

Conversely, if you want a bargraph (where all LEDs will light on full scale), then bridge the Bar links located near the PCB edge (there are nine of these, too).

You may need to use short bits of resistor lead offcuts to bridge the two PCB pads if you find you can't do it with solder alone.

Having done that, install the capacitors. There are two types used in the circuit: MKT polyester and electrolytic.

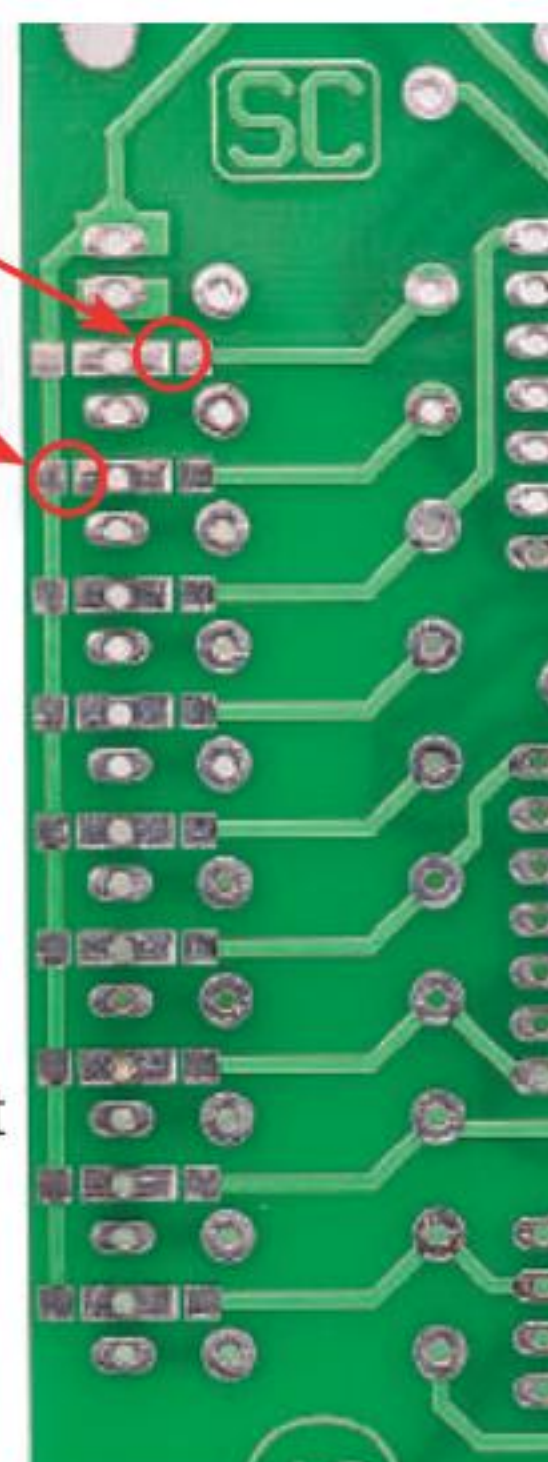
The MKT polyester types can be recognised by their rectangular prism shape and plastic coating. The second are electrolytic and are cylindrical in shape. They have a polarity stripe along one side for the negative lead (also note, the positive lead is longer than the negative lead).

The electrolytic capacitors must be inserted with the correct polarity

TO SELECT DOT MODE, SHORT OUT THESE PADS WITH SOLDER (ON ALL LEDS 1-9)

TO SELECT BAR MODE, SHORT OUT THESE PADS WITH SOLDER (ON ALL LEDS 1-9)

Here's the area of the main PCB where you select the dot or bar graph mode (right under the LEDs). Simply short out the appropriate pads, as indicated. If you can't get solder to bridge across the gaps, use short lengths of resistor lead offcuts.



Scale:	Linear	Log	VU
R10	1kΩ	6.8kΩ	1.1kΩ
R9	1kΩ	4.7kΩ	1kΩ
R8	1kΩ	3.3kΩ	820Ω
R7	1kΩ	2.2kΩ	750Ω
R6	1kΩ	1.6kΩ	1.3kΩ
R5	1kΩ	1.2kΩ	1kΩ
R4	1kΩ	820Ω	820Ω
R3	1kΩ	560Ω	910Ω
R2	1kΩ	430Ω	1.5kΩ
R1	1kΩ	1kΩ	680Ω

Table 1 – Values for resistors R1-R10.

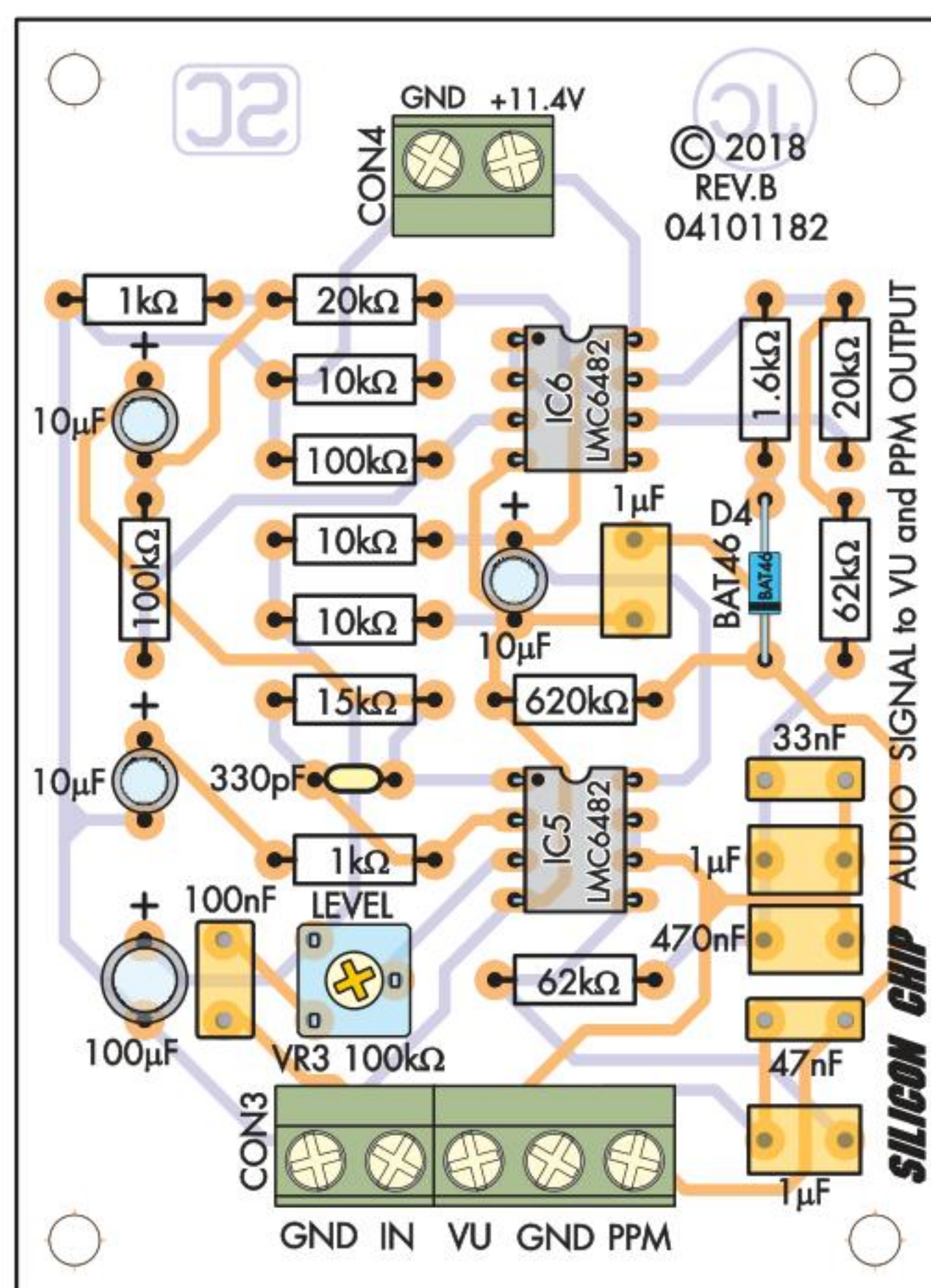


Fig.6: same-size PCB overlay and matching photo of the audio signal processor board, which drives the main display PCB in either VU or PPM modes.

uses a ceramic capacitor, which will normally look like a disc and is not polarised. Then fit the IC sockets for IC5 and IC6; as before, making sure the notched end goes towards the pin 1 dot, as shown in Fig.6.

Follow with trimpot VR3, which may be marked as '104' rather than '100k'. Then install terminal blocks CON3 and CON4, again with their wire entry holes towards the closest edge of the PCB. CON3 is made by dovetailing a 3-way and 2-way screw connector together before inserting them into the board and soldering the pins.

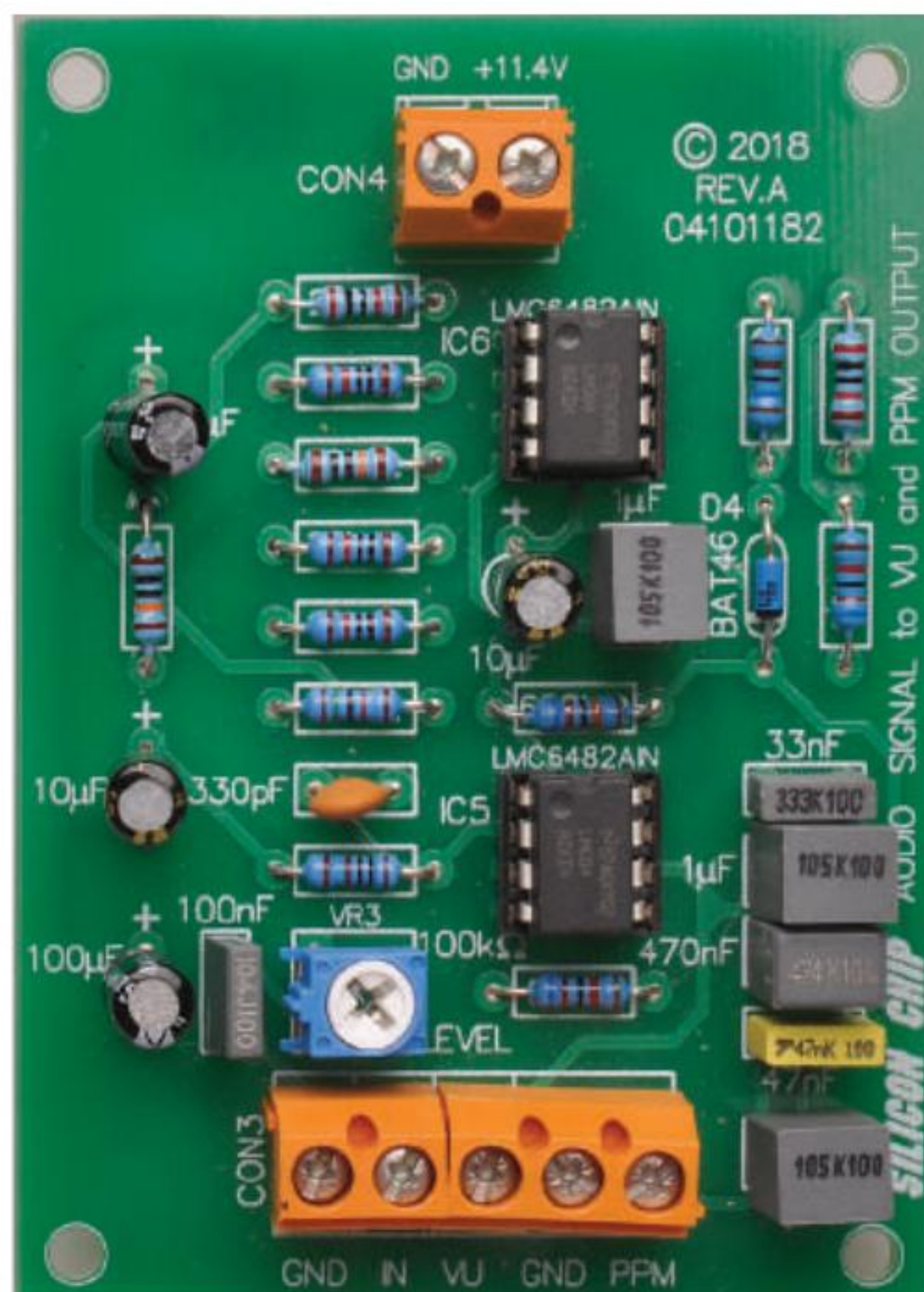
Finally, insert the two ICs into their sockets, making sure that they are both oriented correctly.

Testing and setting up

Before powering up, check your construction carefully and in particular, check the orientation of the ICs and electrolytic capacitors and diodes. It is a good idea to test the *10-LED Bargraph* PCB by itself first, even if you are going to use the *Signal Processing* board later.

Use a 10kΩ linear potentiometer connected as shown in Fig.7 for testing. Connect the power supply between the +12V and GND inputs but do not switch it on yet. Adjust VR2 so that the voltage between TP10 and GND is 10V and rotate VR1 fully anticlockwise for minimum gain from IC1a.

Switch on power and the LEDs should all light when the test potentiometer is rotated near fully clockwise and they should all be off when it is fully anticlockwise. LEDs should sequentially light up as the potentiometer is rotated clockwise, one at a time if dot mode was selected or in a bar otherwise.



You can check that the reference voltages are correct at test points TP1 to TP10. Table 2 shows the voltages expected at these test points for a 10V reference at TP10. The voltages should be within about 10% of the value shown in the table.

As you wind VR2 fully anticlockwise, you will find that the top LED will light with only about half full clockwise rotation. That is because the

reference voltage for the *10-LED Bargraph* is below 5V and so the output from the potentiometer only needs to be this high for the top LED to light.

Similarly, if VR1 is rotated fully clockwise to amplify the potentiometer signal by about a factor of four, the amount of travel required from the potentiometer for a full-scale display will be small. It will be around one-eighth full rotation (clockwise) from an initial fully anticlockwise setting.

If you're using the *Signal Processing* board and the *10-LED Bargraph* board has checked out so far, you can now wire the two together, as shown in Fig.8. To calibrate it, apply a 250mV RMS audio signal to the signal input and set VR3 fully clockwise. Adjust VR2 for 10V at TP10 and adjust VR1 so the display just lights LED10.

You can then apply a line-level audio signal to the input to see the display vary. Note that VR3 will need to be adjusted to reduce the line-level voltage to a suitable level for monitoring on the bargraph.

Line-level signals can vary over a wide range, from around 315mV RMS full scale up to 1.228V RMS, with some devices such as CD, DVD and Blu-ray players producing in excess of 2V RMS.

To make an accurate VU meter, the 0VU level (LED7) should be set to light

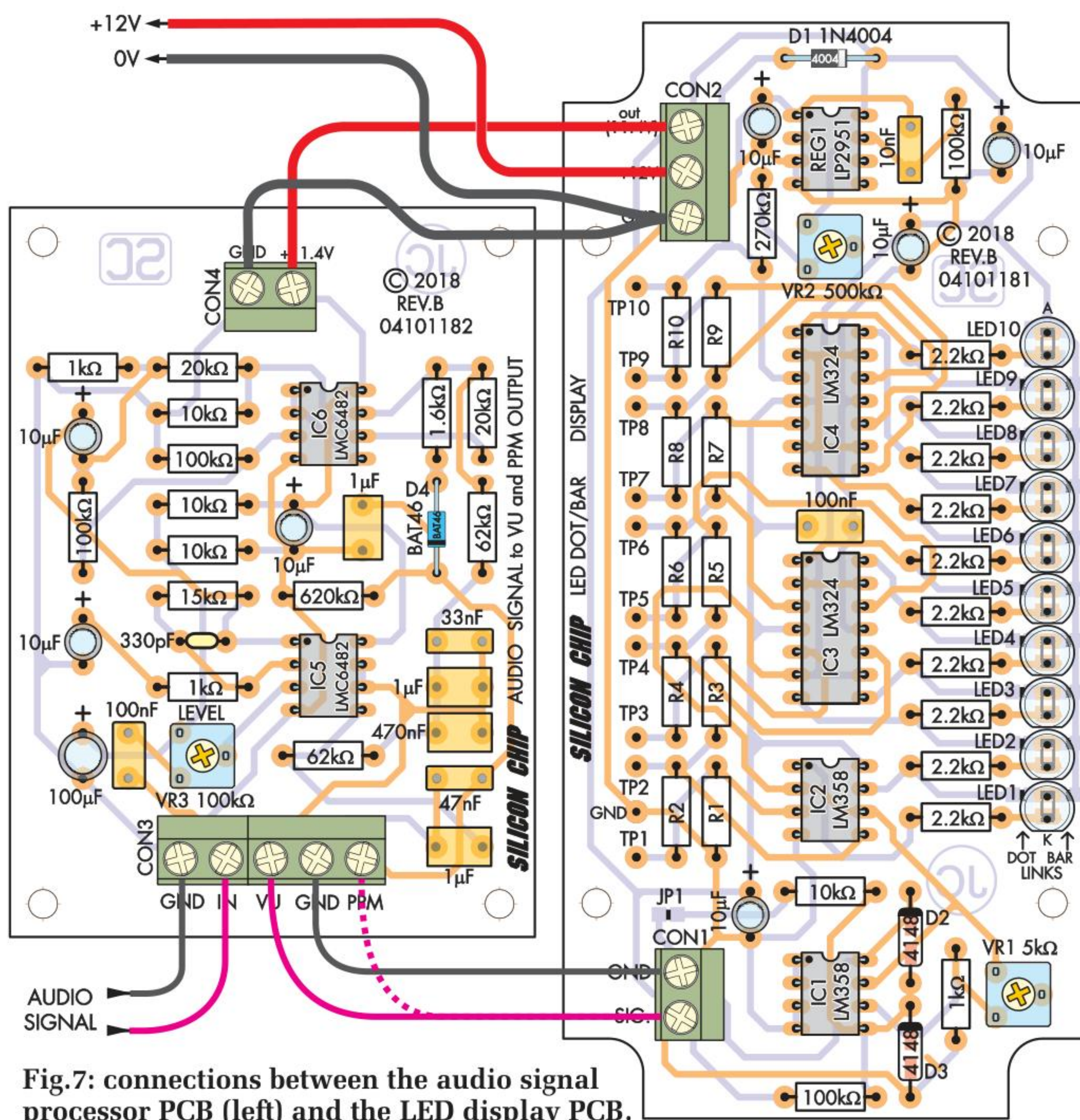


Fig.7: connections between the audio signal processor PCB (left) and the LED display PCB.

	Linear	Log	VU
TP10	10V	0dB (10V)	+3dB (10V)
TP9	9V	-3dB (7.08V)	+2dB (8.91V)
LED8, TP8	8V	-6dB (5.01V)	+1dB (7.94V)
LED7, TP7	7V	-9dB (3.55V)	0dB (7.08V)
LED6, TP6	6V	-12dB (2.51V)	-1dB (6.31V)
LED5, TP5	5V	-15dB (1.78V)	-3dB (5.01V)
LED4, TP4	4V	-18dB (1.26V)	-5dB (3.98V)
LED3, TP3	3V	-21dB (0.89V)	-7dB (3.16V)
LED2, TP2	2V	-24dB (0.63V)	-10dB (2.24V)
LED1, TP1	1V	-27dB (0.417V)	-20dB (0.71V)

Table 2 – Test point voltages/ signal thresholds.

with a 1.228V RMS signal applied to the audio signal input.

This level can be measured using a multimeter set to read AC Volts and a signal generator set to a frequency that the multimeter will measure accurately.

Typically, multimeters will accurately read 50Hz signals but some

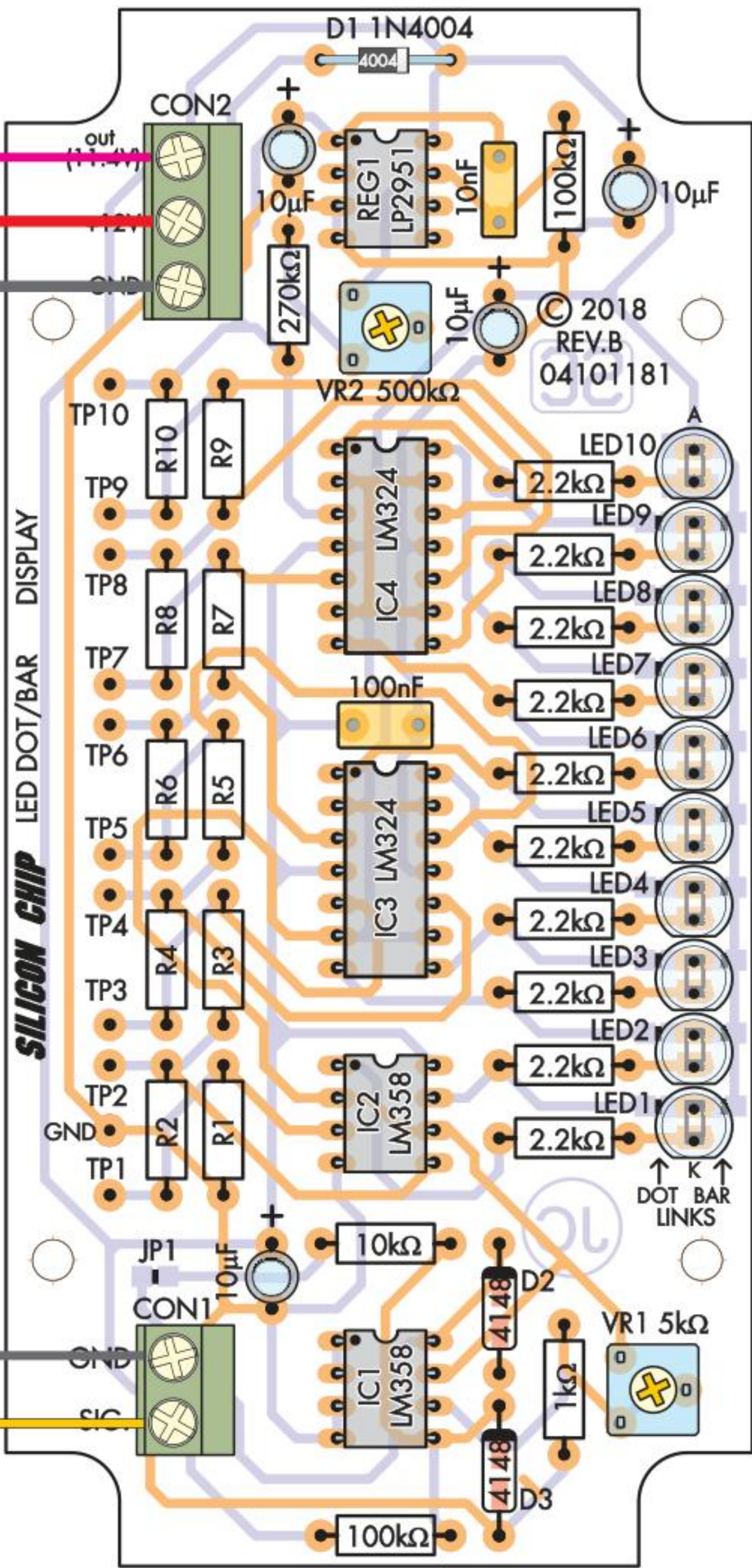
Reproduced by arrangement with
SILICON CHIP magazine 2019.
www.siliconchip.com.au

Fig.8: test setup connections, using a 10kΩ linear pot, to ensure that all LEDs light up at the right points. Voltages for the various test points are shown at left.

10kΩ LINEAR POTENTIOMETER

may measure above 1kHz. Check your meter's specifications before setting the signal generator frequency.

In practice, the sensitivity of the VU meter (or PPM) meter should be



adjusted to set the range for the audio signal that's being monitored.

FANTASTIC MODERN POWER SUPPLY ONLY IU HIGH PROGRAMMABLE

LAMBDA GENESYS PSU GEN100-15 100V 15A Boxed As New	£325
LAMBDA GENESYS PSU GEN50-30 50V 30A	£325

IFR 2025	Signal Generator 9kHz - 2.51GHz Opt 04/11	£900
Marconi 2955B	Radio Communications Test Set	£800
R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£350
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHZ-20GHZ	£2,000
HP83731A	Synthesised Signal Generator 1-20GHZ	£1,800
HP8484A	Power Sensor 0.01-18GHZ 3nW-10uW	£75
HP8560A	Spectrum Analyser Synthesised 50HZ - 2.9GHZ	£1,250
HP8560E	Spectrum Analyser Synthesised 30HZ - 2.9GHZ	£1,750
HP8563A	Spectrum Analyser Synthesised 9KHZ-22GHZ	£2,250
HP8566B	Spectrum Analysyer 100HZ-22GHZ	£1,200
HP8662A	RF Generator 10KHZ - 1280MHZ	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10KHZ-1.01GHZ	£325
Marconi 2024	Synthesised Signal Generator 9KHZ-2.4GHZ	£800
Marconi 2030	Synthesised Signal Generator 10KHZ-1.35GHZ	£750
Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHZ	£295
Marconi 2945/A/B	Communications Test Set Various Options	£2,000 - £3,750
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHZ-20GHZ	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B with	6910 Power Meter	£295

Tektronix TDS3052B/C	Oscilloscope 500MHZ 2.5GS/S	£1,500
Tektronix TDS3032	Oscilloscope 300MHZ 2.5GS/S	£995
Tektronix TDS3012	Oscilloscope 2 Channel 100MHZ 1.25GS/S	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHZ 100MS/S	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHZ	£600
Farnell AP60/50	PSU 0-60V 0-50A 1KW Switch Mode	£195
Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
Fluke 97	Scopemeter 2 Channel 50MHZ 25MS/S	£75
Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
Gigatronics 7100	Synthesised Signal Generator 10MHZ-20GHZ	£1,950
Seaward Nova	PAT Tester	£95
Solartron 7150/PLUS	6 1/2 Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160-£200
Thurlby TG210	Function Generator 0.002-2MHZ TTL etc Kenwood Badged	£65
HP33120A	Function Generator 100 microHZ-15MHZ	£260-£300
HP53131A	Universal Counter 3GHZ Boxed unused	£500
HP53131A	Universal Counter 225MHZ	£350

INDUSTRY STANDARD DMM ONLY
£325 OR £275 WITHOUT HANDLE
AND BUMPERS

HP 34401A Digital Multimeter 6 1/2 Digit

YES! AN HP 100MHZ SCOPE FOR
ONLY £75 OR COMPLETE WITH ALL
ACCESSORIES £125

HP 54600B Oscilloscope Analogue/Digital
Dual Trace 100MHZ

STEWART OF READING
17A King Street, Mortimer, near Reading, RG7 3RS
Telephone: 0118 933 1111 Fax: 0118 9331275
USED ELECTRONIC TEST EQUIPMENT
Check website www.stewart-of-reading.co.uk
(ALL PRICES PLUS CARRIAGE & VAT)
Please check availability before ordering or calling in

Win a Microchip MPLAB PICkit 4 In-Circuit Debugger

Everyday Practical Electronics is offering its readers the chance to win a Microchip MPLAB PICkit 4 In-Circuit Debugger (PG164140).

The Microchip MPLAB PICkit 4 In-Circuit Debugger allows fast and easy debugging and programming of PIC and dsPIC Flash microcontrollers using the powerful graphical user interface of the MPLAB X Integrated Development Environment (IDE).

The MPLAB PICkit 4 programs faster than its predecessor with a powerful 32-bit 300MHz SAME70 MCU and comes ready to support PIC and dsPIC MCU devices. Along with a wider target voltage, the PICkit 4 supports advanced interfaces such as 4-wire JTAG and Serial Wire Debug with streaming Data Gateway, while being backward compatible for demo boards, headers and target systems using 2-wire JTAG and ICSP.

Key features of the PICkit 4 include matching silicon clocking speed, supplying up to 50mA of power to the target, a minimal current consumption at <100µA from target, and an option to be self-powered from the target.

**Worth
\$48.50
(approx £38.00)
each**

The MPLAB PICkit 4 is connected to the design engineer's computer using a high-speed USB 2.0 interface and can be connected to the target via an 8-pin single in-line (SIL) connector. The connector uses two device I/O pins and the reset line to implement in-circuit debugging and in-circuit serial programming (ICSP).

Currently, the MPLAB PICkit 4 In-Circuit Debugger/Programmer supports many but not all PIC MCUs and dsPIC DSCs, but it is being continually upgraded to add support for new devices.

**Free-to-enter
competition**

Microchip
MPLAB PICkit 4
In-Circuit Debugger



How to enter

For your chance to win a Microchip MPLAB PICkit 4 In-Circuit Debugger, visit:

<http://page.microchip.com/EPE-PICkit-4.html>

Closing date

The closing date for this offer is 31 March 2019.

November 2018 winner

Brian Fairchild

He won a SAMA5D2 Xplained Ultra board valued at \$150.

• Arduino based • Low cost • Easy to build • Little or no experience needed!



EARTHQUAKE Early Warning Alarm

Concept by Allan Linton-Smith • Circuit and software by Nicholas Vinen

Earthquakes can strike anywhere... and usually with very little warning. But now there are ways that you get an early warning, which may mean the difference between getting to safety (eg, an open area) and possible injury or death. So how do you go about getting these early warnings of impending earthquakes? Read on...

Probably the easiest way to get earthquake warnings is to install an early warning app on your smartphone. The idea is that a network of seismographic sensors based around the world will pick up an earthquake soon after it occurs and determine its location (based on triangulation), depth and magnitude. The app receives this data within seconds and compares it to your location.

Depending on your proximity to the earthquake and its magnitude, it can generate an alert, seconds or even minutes before the destructive waves of the earthquake arrive.

However, this does rely on a few things working properly: you have to have a smartphone, it has to be charged and switched on, it has to have a working internet connection, the app needs to be installed and running properly.

And there's also the fact that, depending on where the seismic sensors are located geographically, significant time could pass before the alert is even raised.

We installed some popular earthquake early warning apps and set them up to warn us about earthquakes around the world. (There are, literally, hundreds of earthquakes occurring

every day – only the largest make the six o'clock news.)

Timing!

We found that we sometimes got alerts many minutes after an earthquake had occurred – somewhat pointless, you'd agree!

Of course, even if the warning is timely, you might not hear the alert or you may not look at the screen straight away.

Fortunately, there's another option and it may be much more useful, because it doesn't rely on remote seismic sensors, an internet connection or any

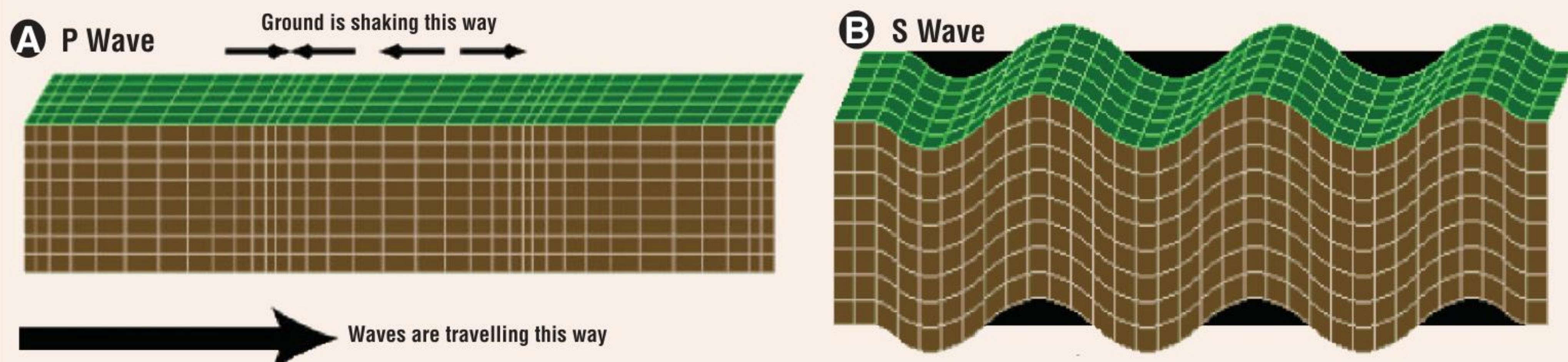


Fig.1: the four different waves caused by an earthquake. In order of fastest to slowest: (a) the P-wave is a compression wave, (b) the S-wave is up-and-down and/or side-to-side motion.



A commercial earthquake early warning alarm, the FREQL (Fast Response Equipment against Quake Load), as used by rescue teams in earthquake areas. Ours is very much simpler... and cheaper!



Here's another commercial detector – the Chinese-made XYB01A. It's not intended for first-responder use; in fact, it's designed for home use, mounted on a wall as shown. We found it tricky to set up and use.

software. And you don't even need to own a smartphone.

Early warning using P-waves

Earthquakes cause a disturbance in the Earth's crust that you can feel. They are generally caused by a sudden rock fracture where the pressure has built up at the junction of two tectonic plates due to continental drift.

When this energy is suddenly released, it causes waves to travel through the Earth's crust away from the location of the fracture.

You may not realise it but a single seismic event can cause at least four different waves to travel through the Earth and shake the ground beneath your feet.

Unless you are very close to the epicentre, these waves will arrive at different times and they will have different strengths and effects.

The first wave to arrive is the pressure wave or P-wave. This travels in a similar manner to the way sound travels through air – see Fig.1(a).

Part of the reason why it arrives first is that it can travel through solids and liquids, so it can take a direct path through the Earth to your location (ie, it doesn't have to follow the curvature of the Earth, despite the fact

that there are liquid layers under the Earth's crust).

The P-wave is usually not terribly strong nor destructive, but it certainly can be detected using seismic monitoring equipment and this will give you the most warning before the destructive waves arrive at your location.

The secondary wave is known as the S-wave and this is caused by rock particles moving side-to-side or up and down, similarly to the way that a wave travels through deep water – see Fig.1(b). Because the S-wave cannot travel through liquid, it cannot pass through the Earth's outer core and so generally arrives after the P-wave. It is usually strong enough to be felt but is not the most destructive wave.

The third wave to arrive is the Love wave (named after AEH Love) – see Fig.1(c). This is the fastest surface wave and is caused by the surface of the Earth moving side-to-side.

Because it has to travel along the surface, it takes the longest path and therefore arrives after the S-wave and P-wave.

Shortly after the Love wave comes the Rayleigh wave, which also travels along the surface. It causes vertical motion as the ground 'rolls', much like waves in shallow water – see

Fig.1(d). This is the wave which is normally felt the most and causes the most destruction.

The relative speeds of the P-waves, S-waves and surface waves can be seen in the seismograph plot of Fig.2. Fig.3 gives more detailed information on the relative speeds of P-waves and S-waves, while Fig.4 shows how the P-waves and S-waves travel at different speeds through different parts of the Earth's crust.

Notice that the P-wave velocity is always higher than the S-wave velocity, so in most cases it will arrive much earlier.

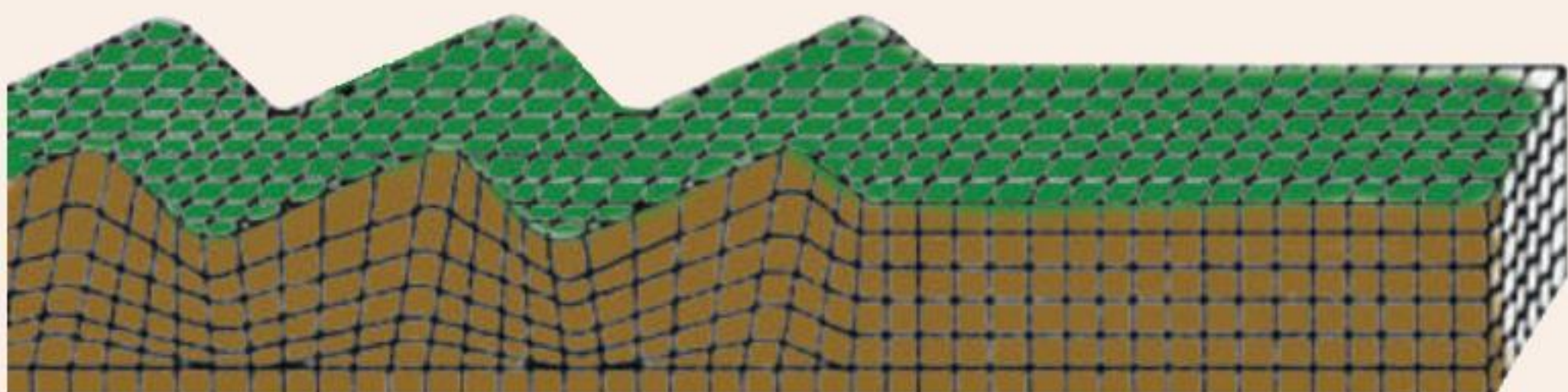
Fig.3 shows how long a typical P-wave and S-wave take to reach a certain distance from the epicentre. As you can see, the S-wave takes around twice as long to reach a given point compared to the P-wave.

If we can detect the passage of the P-wave, then the interval between these two lines is the amount of warning we get before the larger S-wave arrives.

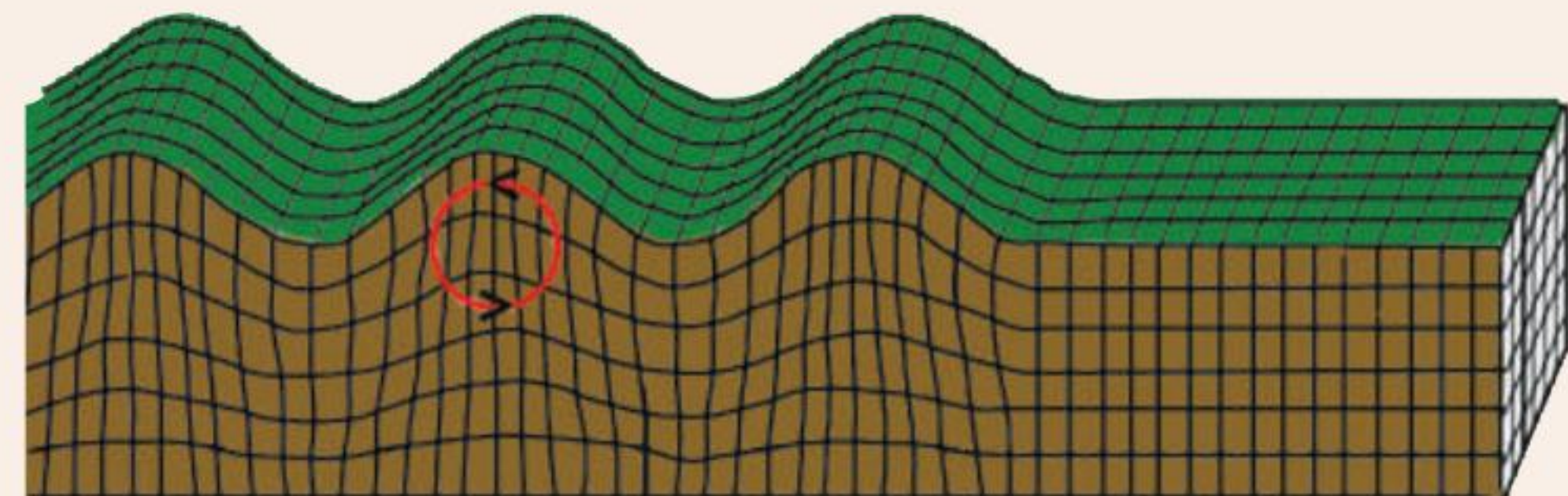
For example, if you are 200km from the epicentre, you would get around 30 seconds' warning, while if you are 2000km away, you will get around five minutes' warning.

Unfortunately, the closer you are, the less warning you will get and the

© Love Wave



© Rayleigh Wave



(c) the Love wave is side-to-side, and (d) the Rayleigh wave has a vertical, rolling action (and tends to be the most damaging). Source: US Geological Survey.

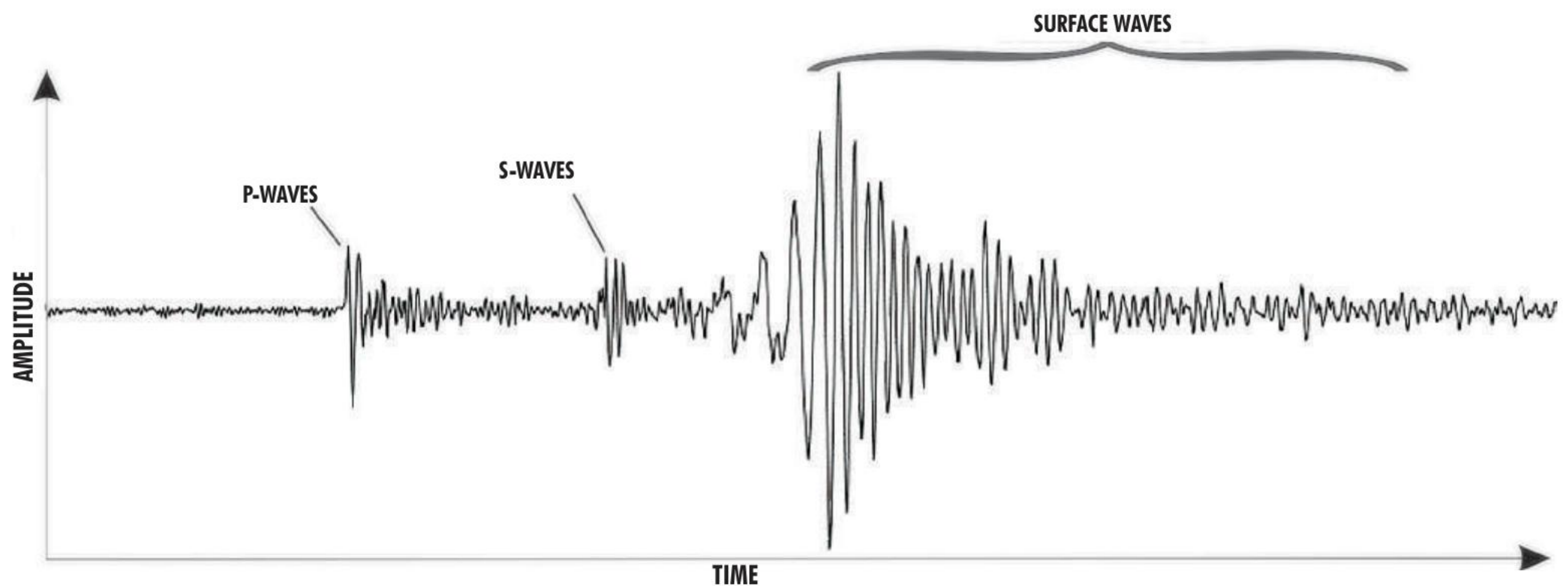


Fig.2: a seismograph plot taken some distance from an earthquake, showing that the P-waves arrive first, then the S-waves, then the surface (Love and Rayleigh) waves. Typically, the surface waves have the greatest amplitude and will be the most destructive. Source: US Geological Survey.

more destruction the earthquake will cause (the waves drop in power as they travel away from the epicentre and expand).

For the most damaging 'quakes, you probably won't get more than one minute of warning.

Detecting the P-wave

Commercial P-wave detector devices do exist. One example is the portable FREQL (Fast Response Equipment against Quake Load). This is used by rescue teams and fire departments in Japan and is especially useful for early warning of dangerous aftershocks during difficult rescue phases. It's shown overleaf.

You can also get consumer-grade devices such as the Chinese-made XYB01A detector. This is a wall-mounted unit which runs from a 9V

battery and uses a pendulum to make contact when a P-wave is experienced, sounding the alarm. It's mechanically adjustable, but a little tricky to set up.

The P-wave normally has a frequency of between one and five hertz (1-5Hz) and could consist of just a short jolt, a series of tremors or a continuous wave, depending on the nature of the earthquake.

So to give you the best chance, the device needs to be as sensitive as possible to signals in that frequency range and with the correct orientation, without being so sensitive that it could be set off by other vibrations.

Our detector

The electronic device we describe here uses a relatively inexpensive but very sensitive accelerometer combined with a regular Arduino board.

Depending on where you live, it may give you enough warning to find a safe place if it detects an oncoming earthquake or aftershock. And it may be useful if you live near an active volcano; volcanoes can generate P-waves prior to eruption.

No promises, of course: but it's much better to have a detector which could give you warning than have no detector and have no chance!

Besides, it's cheap, easy to build and requires very little soldering. You can put it together in about an hour or so, even if you aren't very experienced.

We considered designing the device around analogue circuitry, but P-waves can come from any direction and thus some fairly intense signal processing is required. This is much easier to do with software and it doesn't require a custom-designed PCB.

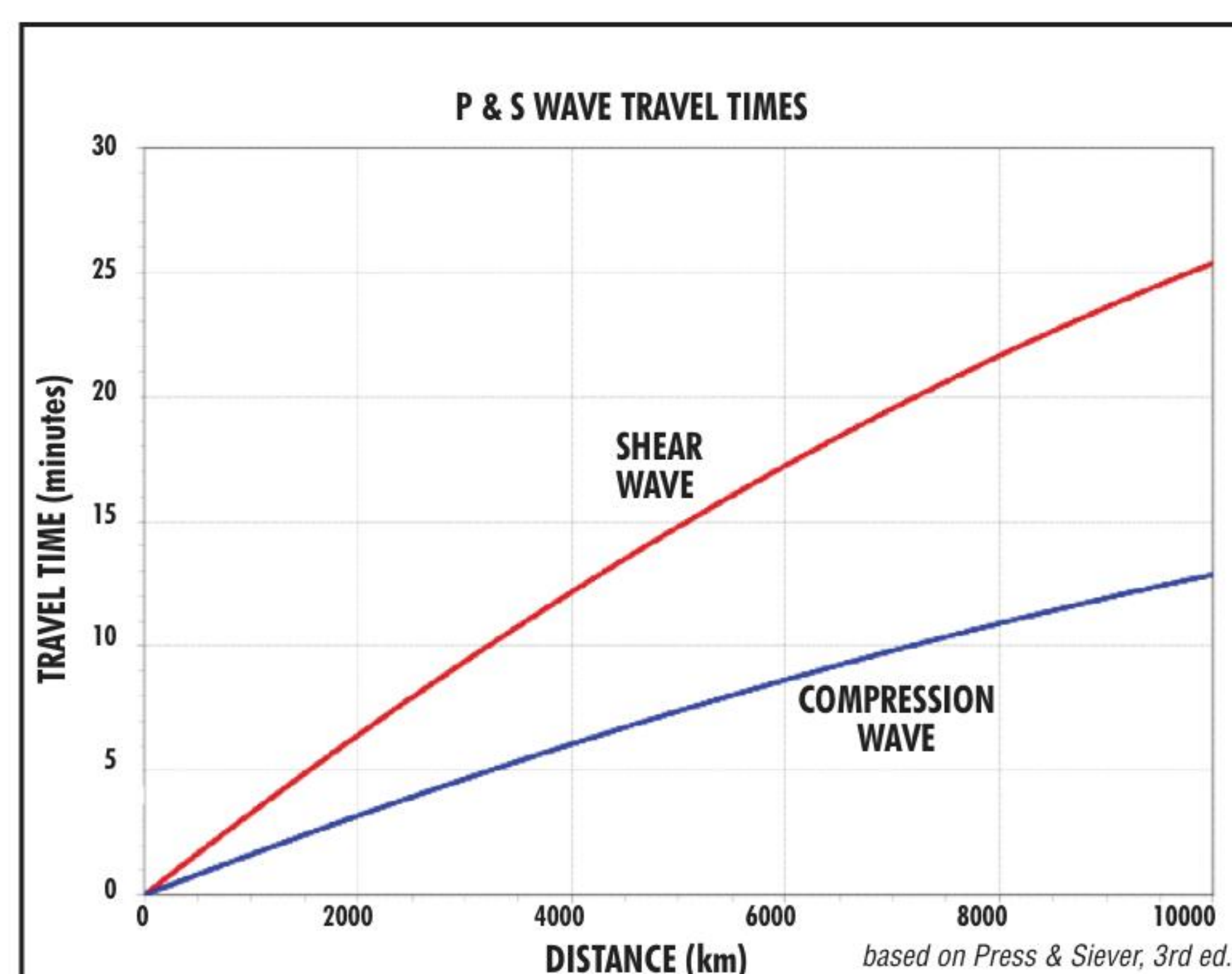


Fig.3: a graph of approximately how long it takes the P-wave and S-wave to reach a point a certain distance from the epicentre. The P-waves travel about twice as fast as the S-waves so they reach the same distance in about half the time. The lines are curved due to the curvature of the Earth.

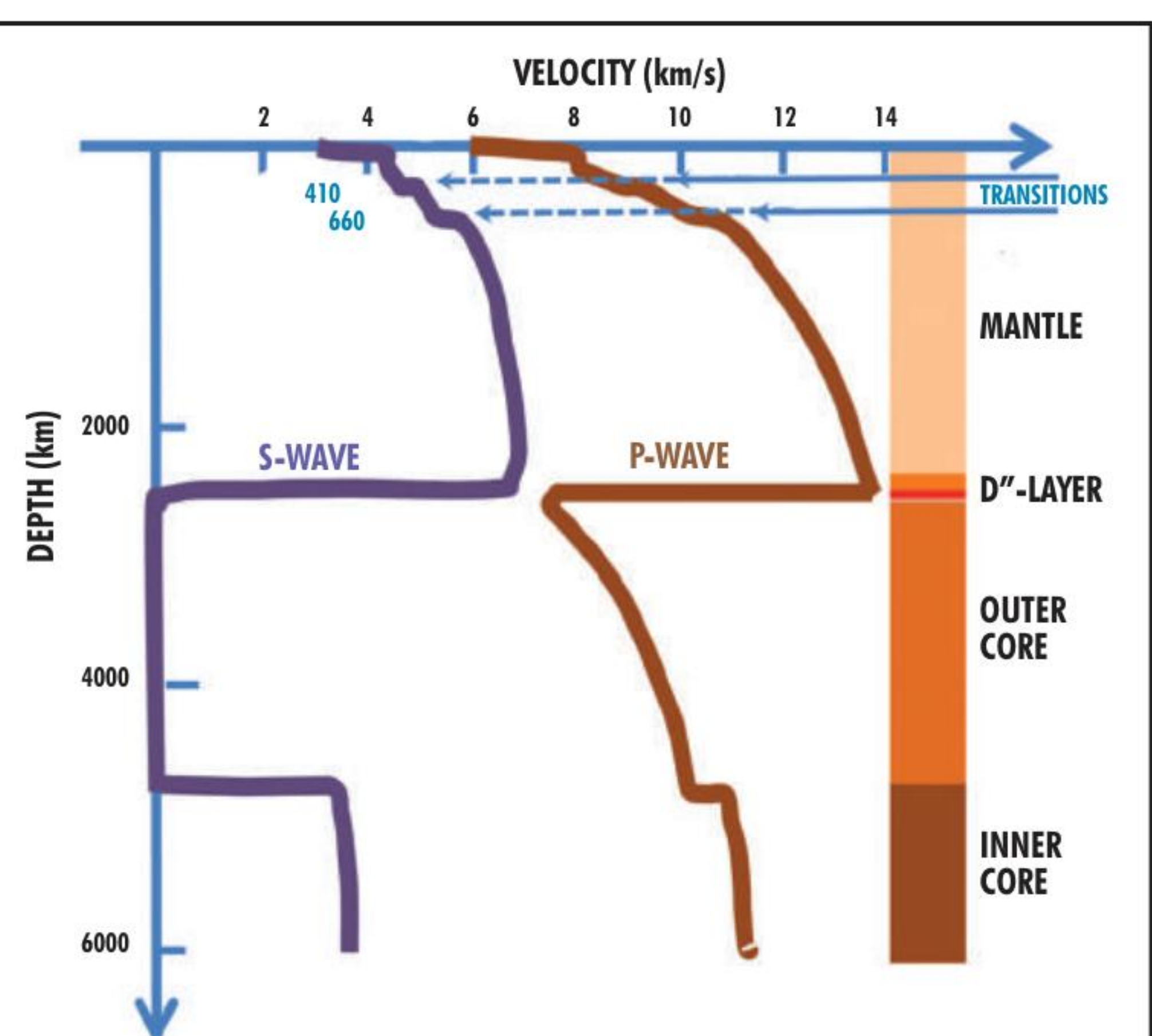


Fig.4: this shows how fast the P-wave and S-wave typically travel at various depths in the Earth's crust. The P-wave travels faster so it will arrive first.

Circuit details

Our circuit is shown in Fig.5. The two main components are the Arduino Uno (or equivalent) board (MOD1) and the Altronics Z6324 digital accelerometer/gyroscope, MOD2.

MOD2 uses the MPU-6050 IC and we've chosen this one in particular because it has an on-board 16-bit analogue-to-digital converter (ADC). Note that we aren't using the gyroscope feature, just the accelerometer.

At maximum sensitivity, the full-scale reading of this device is $\pm 2g$ on each of the three axes and the 16-bit DAC gives a resolution of 0.00006g ($2 \div 32768$).

That's what we need to detect the very small vibrations of a P-wave from a distant source. P-waves are often so faint that you can't feel them with your sense of touch, but this device can potentially detect such small tremors.

One of the handy things about the MPU-6050 is that it has configurable digital low-pass and high-pass filters. The low-pass filter can be configured with a -3dB point of 5Hz, 10Hz, 21Hz, 44Hz, 94Hz, 184Hz or 260Hz. We have chosen 5Hz because this suits our application. Similarly, you can configure it for a high-pass filter of 5Hz, 2.5Hz, 1.25Hz or 0.625Hz.

We have used the last option, giving a response of 0.625-5Hz. We provide an additional 1Hz high-pass filter in the software (which also helps to remove any residual gravity from the readings; for example, if the unit is not mounted perfectly horizontally).

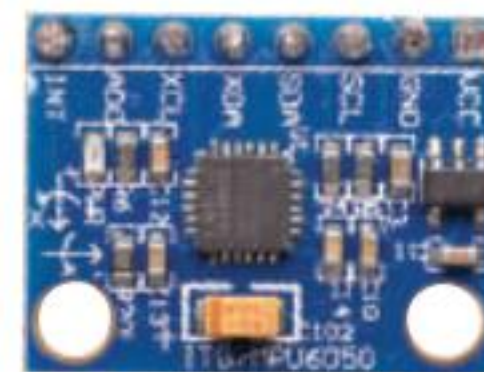
The Arduino makes a couple of dozen readings of the X, Y and Z-axis acceleration figures each second, and after processing them it uses an RMS formula to compute the magnitude of the resulting X/Y low-frequency vector. This is multiplied by a sensitivity factor, set using trimpot VR1, and if it exceeds an arbitrary threshold for more than about 200ms the alarm is triggered.

To sound the alarm, output pin D12 is pulsed high and low at about 1Hz. When high, bright blue LED1 lights up and NPN transistor Q1 is switched on. This triggers the very loud piezo siren. Its volume and pitch are similar to a smoke alarm.

If an S-wave or surface wave is detected (by a similarly large excursion in the magnitude of the Z-axis measurement), LED1 and the piezo siren also light, but they are on continuously, rather than pulsed.

This should alert you to the fact that you are currently experiencing an earthquake, in case the other signs (shaking, falling objects) aren't obvious enough!

The tiny MPU-6050 3-axis accelerometer which is the 'heart' of the project, detecting distant P-waves.



The unit can be mains-powered, via a USB port on a PC; from a DC plugpack; or you can use the optional battery-backed supply (shown as MOD3 at the bottom of Fig.5).

MOD3 consists simply of a single Li-ion/LiPo cell combined with a small charger/power supply board. The battery is kept charged by the USB power supply when mains is present. The battery can power the rest of the circuit for a few hours if there is a blackout.

While we haven't shown a solar panel connected there is provision for one – this could make the whole project fully self contained with solar-backed power if you wished to use it remotely. Virtually any 6V-12V solar panel could be pressed into service – the circuit only draws significant power from the battery when the alarm is going off – at which time a flattening battery is likely to be the least of your concerns!

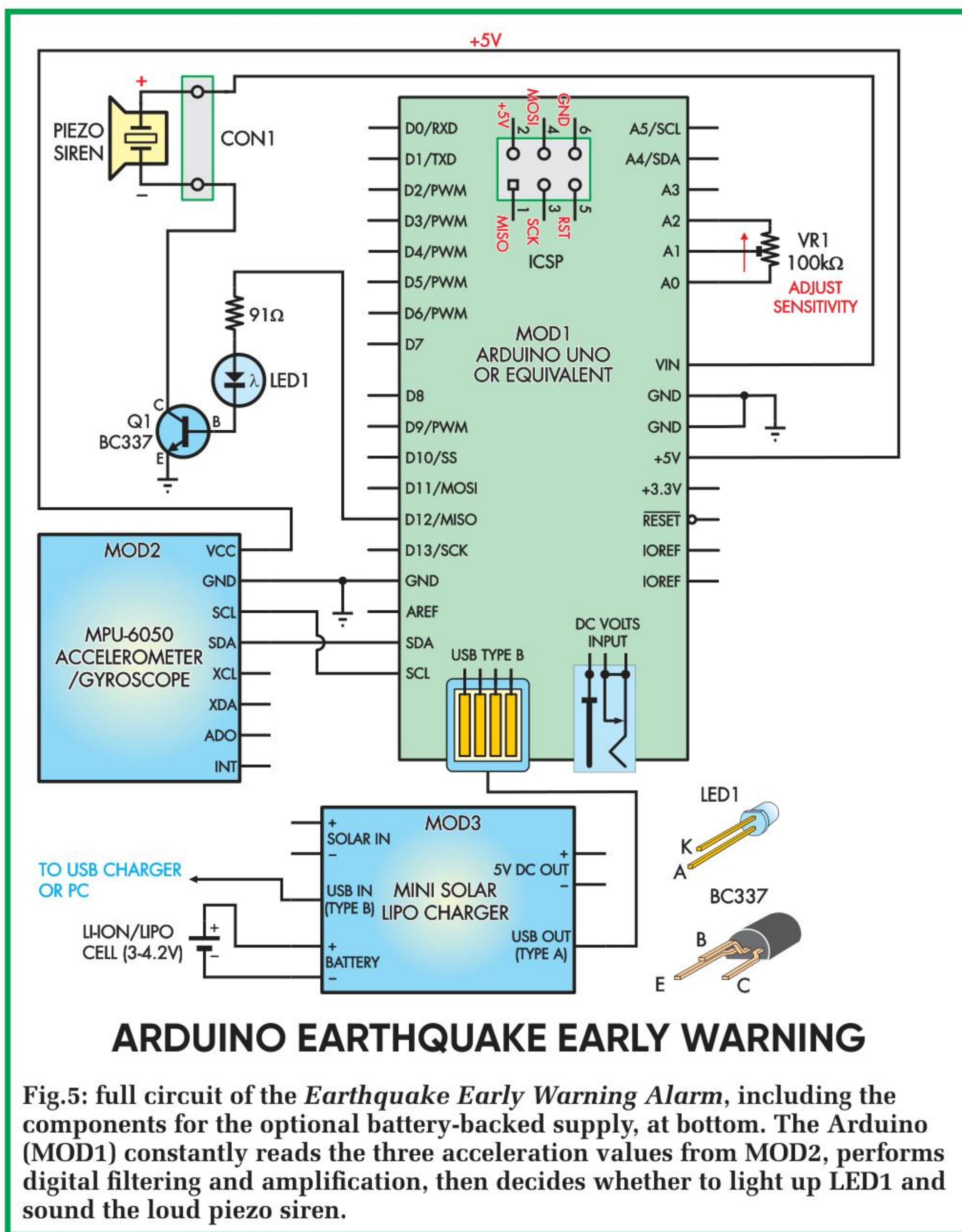
To make construction easy, we wired trimpot VR1 directly to pins A0, A1 and A2. A1 is used as an input, while A0 and A2 are programmed as digital outputs. So we simply pull A2 high (to +5V) and A0 low (to 0V) just before measuring A1.

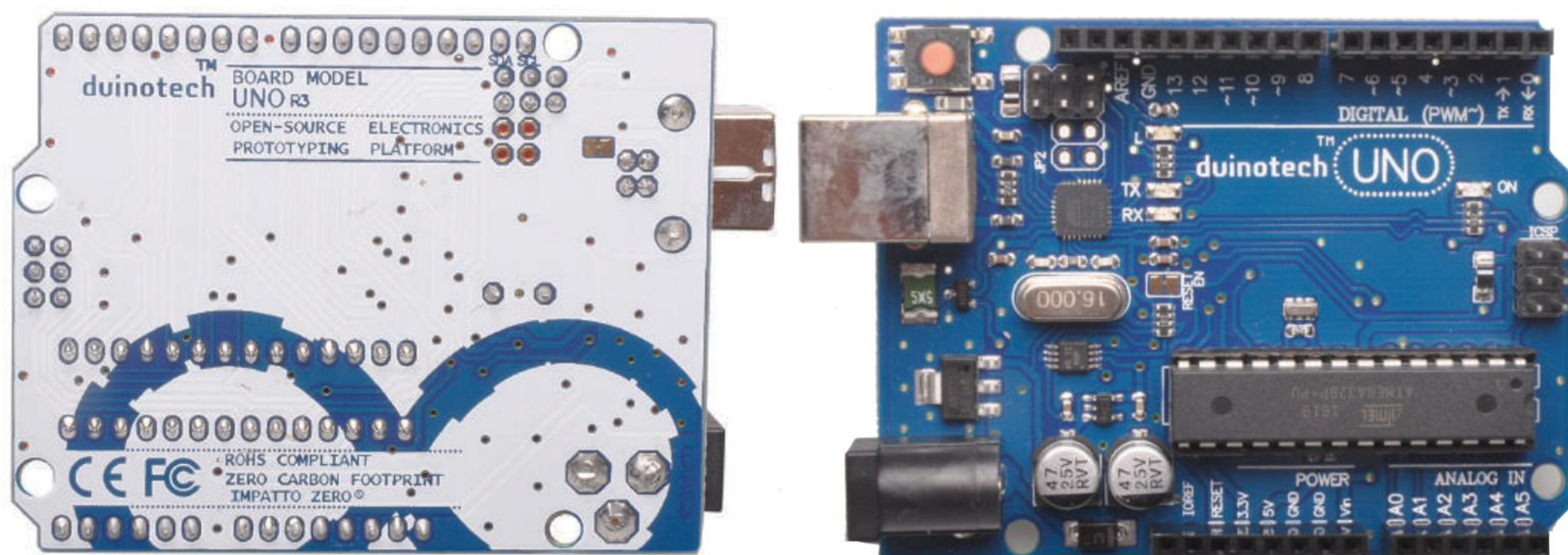
Therefore, we read the position of the trimpot as a digital value and use that to determine the sensitivity. This is computed exponentially so that the full range of rotation of VR1 gives about a 100:1 ratio between the level of vibrations needed to trigger the alarm at its two extremes.

We've set up the sensitivity so that at maximum, the unit will trigger on the tiniest tremor, while at the minimum setting, you'd probably have to hit it with a hammer to set it off.

Also note that to save power and simplify the circuit, we wired the warning LED in series with the base-current-limiting resistor for Q1.

The LED current is around 11mA $[(5V - 3.3V - 0.7V) \div 91\Omega]$. If you use a different colour LED, it will be driven at a slightly higher current, due to its lower forward voltage, but it shouldn't





The two sides of the Arduino Uno board, shown here close to life size (in this case the duinotech UNO from Jaycar – there are several compatible boards). The protoboard (below) simply plugs into the sockets on the edges of the board (opposite).

be necessary to change the resistor value. (If you don't have a 91Ω resistor, 100Ω should be fine).

Construction

While you could build the device by wiring up the various components with flying leads, we used a protoboard to give a neater result, as you can see from the photos.

No component overlay is shown for the protoboard as there are so few components involved – all of the inter-connection details are clearly shown in the photograph.

By soldering connected components close together, we only needed to run five wires, all of which you can see on the top of the board (two 0Ω resistors and three lengths of hookup wire; blue, green and red). Wire links can be used in place of the 0Ω resistors if you prefer. (Wire links are also a tad cheaper!)

Start by soldering an 8-pin header to the MPU-6050 accelerometer module, then solder it to the prototyping shield.

You will need to make four connections between this module and the shield headers: VCC to +5V, GND to

GND, SDA to SDA and SCL to SCL.

Having done that, solder the 91Ω resistor from pin D12 to a pad near the edge of the board, then connect it to the LED anode. Connect the LED cathode to the base (middle pin) of Q1.

The collector of Q1 is the right-most pin when looking at its labelled face and this is connected to 5V. The remaining pin of Q1 goes to the negative pin of the piezo siren via CON1, with the positive pin wired to VIN.

We connected the piezo siren via a 2-pin polarised header. This is handy for testing since the siren is very loud. If it's too loud while you're setting up, it can be temporarily muted by having something placed over its opening (a piece of sticky tape or insulation tape, for example) or placing it upside-down on your bench top.

If you don't want to solder the wires to a plug and the header to the PCB, you can directly solder the piezo wires to the board.

Finally, solder trimpot VR1 to pins A0, A1 and A2, as shown in the photo. That's it – those are all the connections you need. Solder the headers to the

shield board, then put it aside while you program the unit.

Programming it

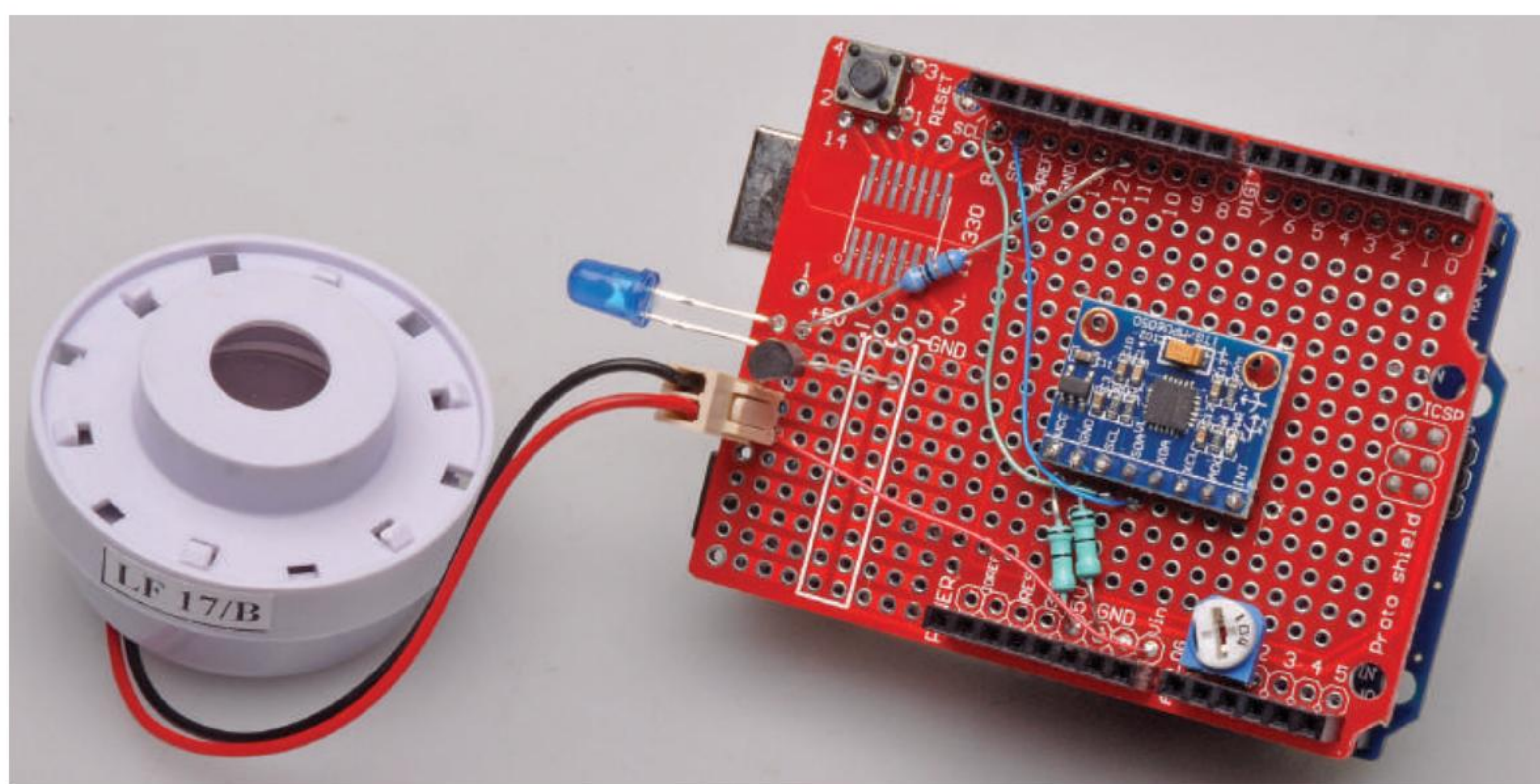
Download the Arduino sketch, named **EarthquakeEarlyWarning.ino** in the project's software package from the *EPE* website. You will also need to have the Arduino IDE installed on your computer. The latest version can be downloaded for Windows, macOS and Linux from: www.arduino.cc/en/Main/Software

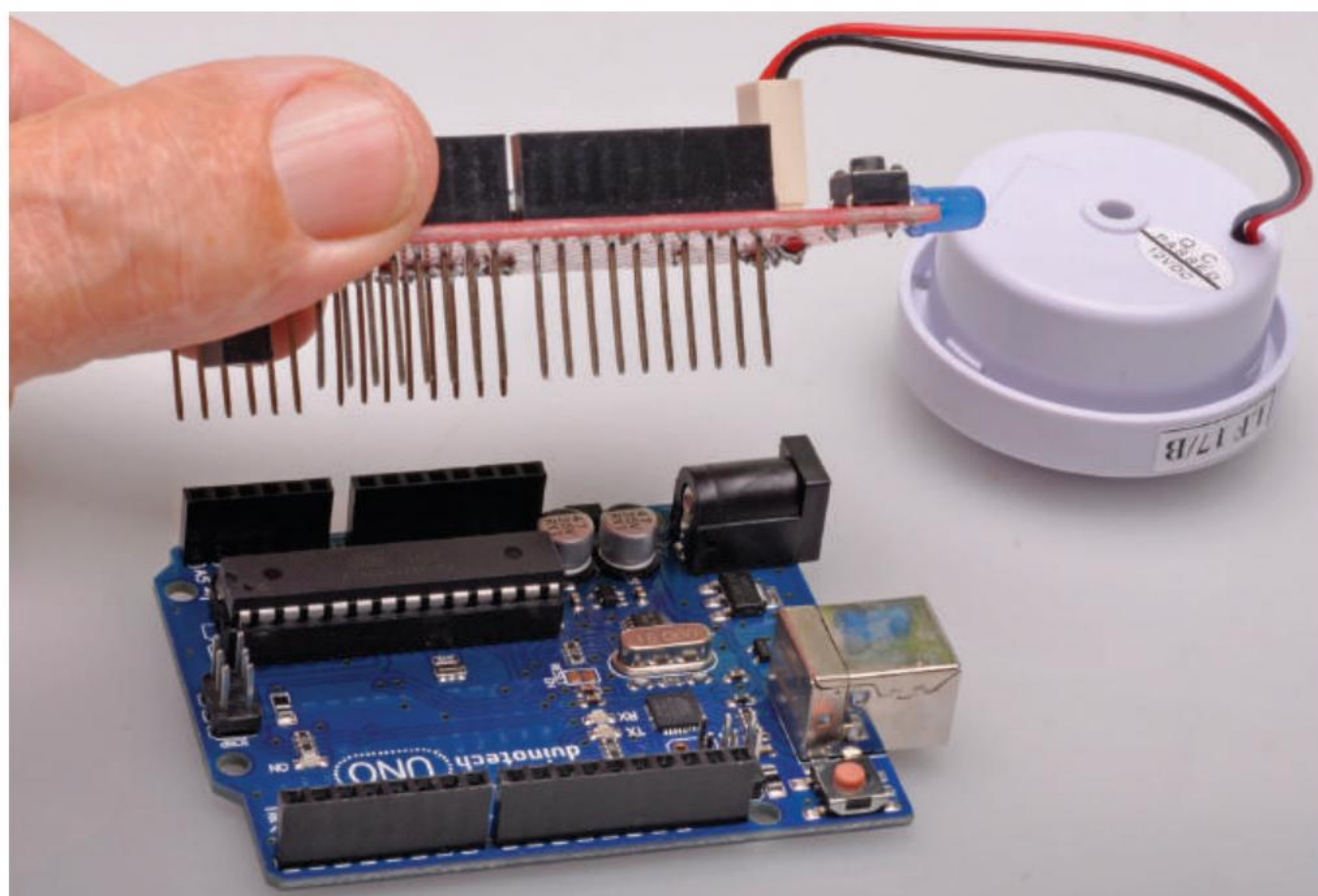
Once it's installed, load it up and open the sketch.

There is one additional library that needs to be installed. It's called 'Filters' and a zip file is included in the download package. Use the Sketch -> Include Library -> Add .ZIP Library menu option to install this file on your system.

Now plug the Arduino into your computer using a USB cable (without the shield, for now) and then go to the Tools menu and make sure the correct Port has been selected. Next, use the Sketch -> Upload command to upload the code to the Arduino module.

Here's the protoboard with the LED, transistor, resistor and trimpot plus the MPU-6050 accelerometer board all mounted, as per the circuit overleaf. This assembly plugs into the Arduino Uno. The two light blue 'resistors' (bottom of PCB) are actually 0Ω links. The piezo 'siren' is rather loud, as you would want it to be if it is to warn you of impending doom! Not shown here is the optional battery and recharger – see full details of this in the article in *EPE*, August 2018.





The two PCBs simply plug into each other via the header pins on the top board and the matching sockets on the Arduino board, as shown here.

Check the output at the bottom of the screen to make sure it has been compiled and uploaded without errors.

You can now unplug the Arduino module from your PC and plug the completed shield into it.

Then plug it back into your PC and open the Serial Monitor in the Arduino IDE. It's available under the Tools menu. Pretty soon, you should see an output like this:

```
|XY| = 0.05, |Z| = 0.11
|XY| = 0.37, |Z| = 0.05
|XY| = 0.17, |Z| = 0.04
|XY| = 0.22, |Z| = 0.29
|XY| = 0.20, |Z| = 0.08
|XY| = 0.27, |Z| = 0.20
|XY| = 0.16, |Z| = 0.21
|XY| = 0.02, |Z| = 0.25
|XY| = 0.42, |Z| = 0.04
```

These are the readings from the accelerometer. $|XY|$ is the dimensionless magnitude of the horizontal AC vector; $|Z|$ is the magnitude of the AC component of the vertical vector.

If you shake the unit, you should see these values temporarily increase, then settle back towards zero. Rotating VR1 clockwise should cause them to increase and with VR1 fully clockwise, even the slightest nudge should cause LED1 to light up and flash.

Assuming it's working, turn VR1 clockwise as far as you can go while ensuring that LED1 remains off when the unit is sitting untouched on a steady surface.

Note that the alarm condition persists for several seconds after any shock, so you will need to make small adjustments and leave the unit alone for a few seconds to see whether the sensitivity is correct.

You can then plug the siren in and check that it sounds when you bump the unit.

Setting it up

Mount the unit inside a box so that it's held firmly in place within that box. The 'noise hole' of the piezo siren (ie, where the sound comes out!) should line up with a similar hole in the box.

The orientation of the electronics doesn't matter, as long as when the device is mounted on a wall (the preferred location), the accelerometer PCB is horizontal.

The device should be firmly fixed to a solid wall and if set correctly, it will sound the alarm when it experiences significant horizontal movement in any direction. Since the wall should be solidly fixed to the ground, that normally will only occur if the ground moves.

Parts list – Earthquake Early Warning Alarm

- 1 Arduino Uno or compatible board (MOD1)
- 1 MPU-6050 based accelerometer/gyroscope module with 8-pin header (MOD2; Altronics Z6324)
- 1 1-13V loud piezo siren (Altronics S6115)
- 1 Arduino prototyping shield PCB and header set
- 1 high-brightness 5mm LED (LED1)
- 1 BC337 NPN transistor (Q1)
- 1 100kΩ mini horizontal trimpot (VR1)
- 1 91Ω 0.25W resistor
- 1 2-pin polarised header and matching plug (CON1)
- Some short lengths of light-duty hookup wire
- 1 small plastic box (eg, UB5 Jiffy box)
- 1 USB charger or other USB power source

Optional parts for battery backup

- 1 solar charger module (eg, CPC09141S from www.aliexpress.com)
- 1 small single-cell Li-ion/LiPO cell
- 1 short USB cable to suit solar charger module
- 1 6-12V mini solar panel, if required

We can't rule out the occasional false alarm due to heavy vehicles, trains, nearby hammer blows or similar, but you can turn VR1 anti-clockwise slightly if you are experiencing false alarms, reducing its sensitivity until they stop.

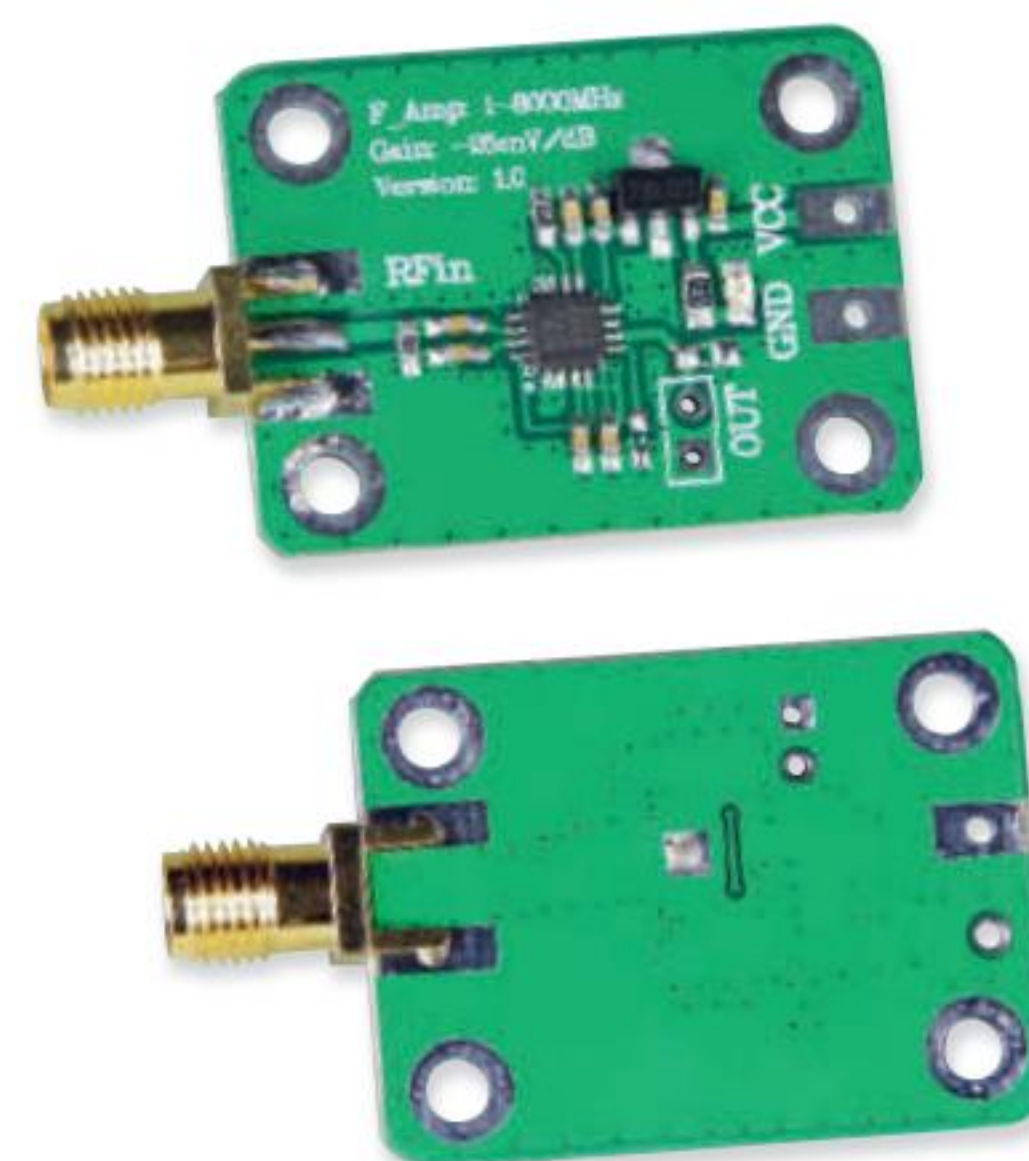
Reproduced by arrangement with
SILICON CHIP magazine 2019.
www.siliconchip.com.au

A cheap 6V-12V solar panel, as shown here, a surplus mobile phone battery (both commonly available on ebay) plus one of the small 'Elecrow' Li-Ion battery charger modules described in *Li-Ion and LiPo Charger Modules* (EPE, August 2018, available

from www.aliexpress.com, item CPC09141S) will make a fine power supply for your Arduino-based *Earthquake Early Warning Alarm*, with the added advantage of making it completely self-contained: no external power supply is required!



Banggood's RF Detector



This nifty *RF Detector* module from Banggood can measure the power of RF signals from 1MHz to 8GHz, over a range of 60dB. It is mounted on a tiny PCB measuring 33 × 24.5mm and has an SMA RF input connector attached to one end. It's based on the Analog Devices AD8318 chip, which is an enhanced version of the AD8307.

This is not the first time we have met the this type of IC. We used the Analog Devices AD8307 chip in the *Arduino Multifunction Measuring Shield* of April-May 2017. Both the AD8318 and AD8307 are logarithmic amplifier/detectors that provide a DC output voltage proportional to the RF input power level.

There are differences between the two devices. The AD8318 has a much wider bandwidth of 1MHz to 8GHz, compared with the DC-500MHz range of the AD8307. While the AD8307 has a range of just over 90dB, the AD8318 has a smaller dynamic range of about 60dB (necessary to get the improved frequency range).

Unlike the AD8307, which operates from a nominal supply voltage of 3V, the AD8318 is designed to operate from 5V. It also has a typical supply current of 68mA, compared with the 7.5mA drawn by the AD8307.

Perhaps the most important functional difference between the two devices is in the output circuitry. The AD8307 has a current mirror in its output, which provides a positive slope to the DC output voltage. So the output voltage is directly proportional to the RF input level, with a slope of 25mV/dB.

In contrast, the AD8318 has a different output circuit designed to allow it to be used for power amplifier gain control. As a result, it provides an output voltage which is inversely proportional to the RF input, with a slope of -25mV/dB. Is this a problem? Not when you are going to use it in conjunction with an Arduino or other microcontroller.

Fig.1 shows a simplified version of the circuitry inside the AD8318. It has nine detector stages, interspersed with eight cascaded gain stages. The nine detector outputs are fed to an adder which drives a current-to-voltage converter to produce the output voltage, V_{OUT} .

The V-I (voltage-to-current) converter at upper right allows adjustment of the slope of V_{OUT} in measurement mode. For example, the output slope of -25mV/dB is achieved when the V_{SET} pin and the V_{OUT} pin are tied together.

Higher output slopes can be obtained by connecting a voltage divider between the V_{OUT} pin and ground, and feeding a fraction of V_{OUT} back to the V_{SET} pin. So if the voltage fed back to V_{SET} is $V_{OUT} \div 2$, this changes the output slope to -50mV/dB.

However, the output voltage is always in the range of 0.5-4.6V, so

beyond -55mV/dB, the dynamic range will be reduced as the output at lower RF levels will be pegged at 4.6V.

Note that the AD8318 includes an internal temperature sensor as well as bias stabilisation circuitry for the cascaded gain stages so that changes in ambient temperature do not unduly affect accuracy.

All this is squeezed into a tiny 4 × 4mm 16-lead LFCSP (SMD) package; much smaller than the 8-pin SOIC/PDIP packages used for the aforementioned AD8307.

Now have a look at the circuit for the Banggood log detector module shown in Fig.2. Apart from the AD8318 chip itself (IC1), there is not much to it. The only other IC is REG1, a 78L05 regulator in an SOT-89 3-pin package with tab.

This provides a regulated 5V rail for IC1. The 78L05 has a nominal

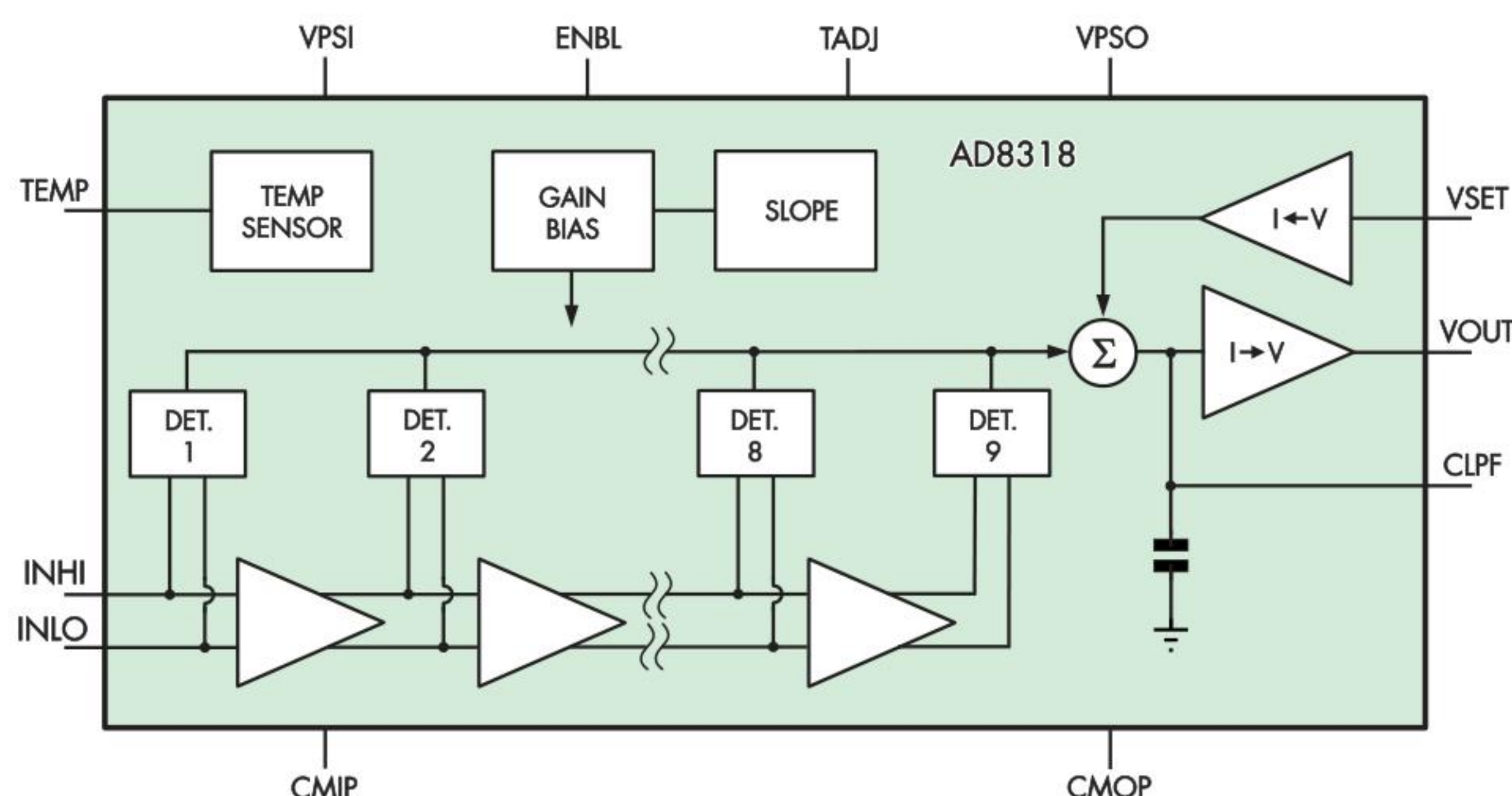
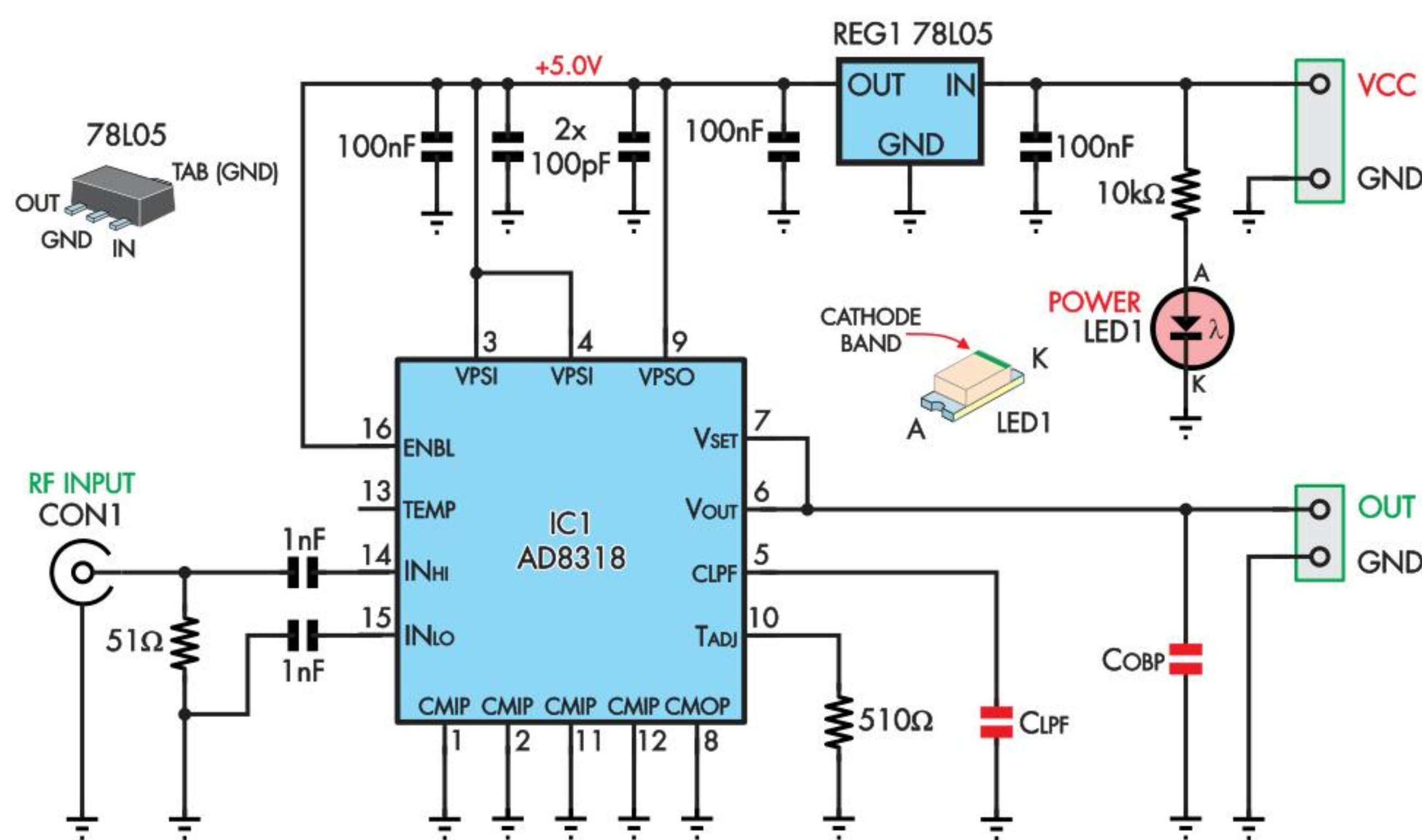


Fig.1: simplified block diagram of the AD8318 logarithmic detector/controller. It has nine detector stages interspersed with eight gain stages.



1MHz – 8GHz LOGARITHMIC DETECTOR MODULE

Fig.2: circuit diagram of the log detector module. C_{LPF} and C_{OBP} are optional capacitors used to filter ripple from IC1's output. Suitable values are 1nF for C_{LPF} and 10nF for C_{OBP} with pads provided for mounting on the PCB.

dropout voltage of 2V, so note that this module needs a power supply (V_{CC}) of at least 7.5V.

As with many other modules, there's one LED to indicate when power is applied. LED1 is connected directly between the V_{CC} input and ground with a 10kΩ series resistor.

CON1 is the RF input, an SMA edge-mount socket. This is terminated via a 51Ω resistor and then coupled to the IN_{HI} input (pin 14) of IC1 via a 1nF capacitor, with a second 1nF capacitor coupling the IN_{LO} pin of IC1 (pin 15) to ground.

The input resistance of IC1 between pins 14 and 15 is close to 1200Ω, so this gives the input circuit a low-frequency cutoff of around 300kHz. The effective input resistance at frequencies below about 100MHz is around 49Ω (51Ω || 1200Ω).

Pin 16 of IC1 is the enable input, which can be used to switch the device into a low-current standby mode

if needed, by pulling it to ground. However, in the Banggood module, it's connected to the +5V line, so the chip always functions while the module is powered up.

So what's the purpose of that 510Ω resistor connected between pin 10 (T_{adj}) of IC1 and ground? It allows adjustment of the chip's internal temperature compensation, to optimise its operation at different frequencies. A value of 510Ω apparently gives very close to optimum compensation at frequencies up to 2.2GHz, and also at 8GHz, while optimum operation at 3.6GHz and 5.8GHz can be achieved by changing R_{Tadj} to 51Ω or 1kΩ, respectively.

Do note though, a value of 510Ω apparently gives acceptable performance over the whole range.

The two capacitors shown in red (C_{LPF} and C_{OBP}) are used for filtering any ripple in the output from IC1. If both capacitors are omitted, the nominal output video bandwidth of the AD8318 is

around 45MHz, making it suitable for demodulating pulse signals.

If you're using it purely for measuring *unmodulated* RF, then this wide bandwidth can allow significant second-harmonic ripple to appear in the output for input signals below 22MHz. Since this ripple can cause measurement jitter, the simplest way to reduce its effect is to add either C_{LPF} or C_{OBP} , or both. A suitable value for C_{LPF} is 1nF, while that for C_{OBP} is around 10nF, and these values give an output bandwidth of around 100kHz.

By the way, neither of these capacitors are fitted to the module board (even though pads are provided for fitting them as 0603 SMD components) which is why we've shown them in red in Fig.2.

Trying it out

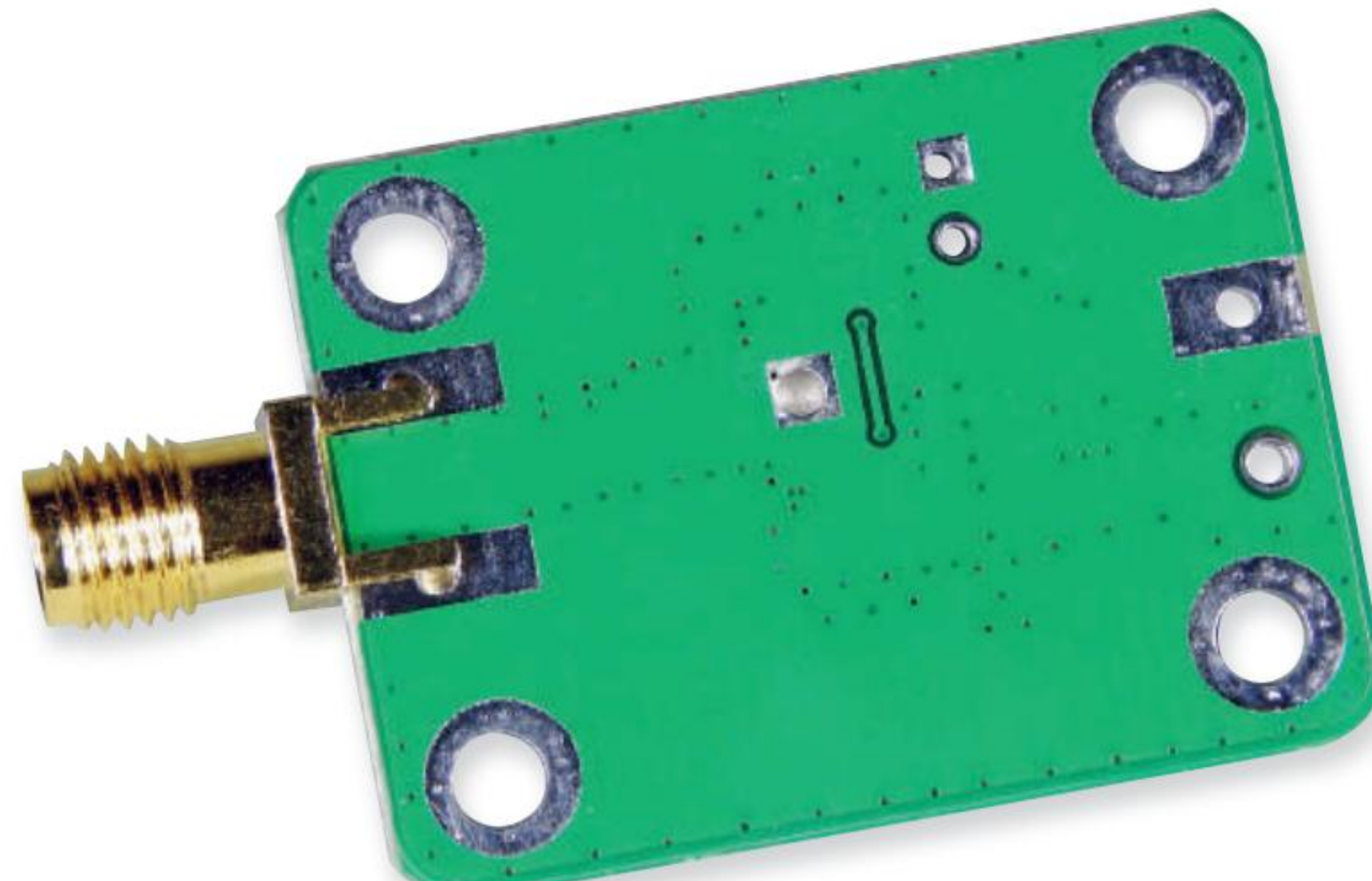
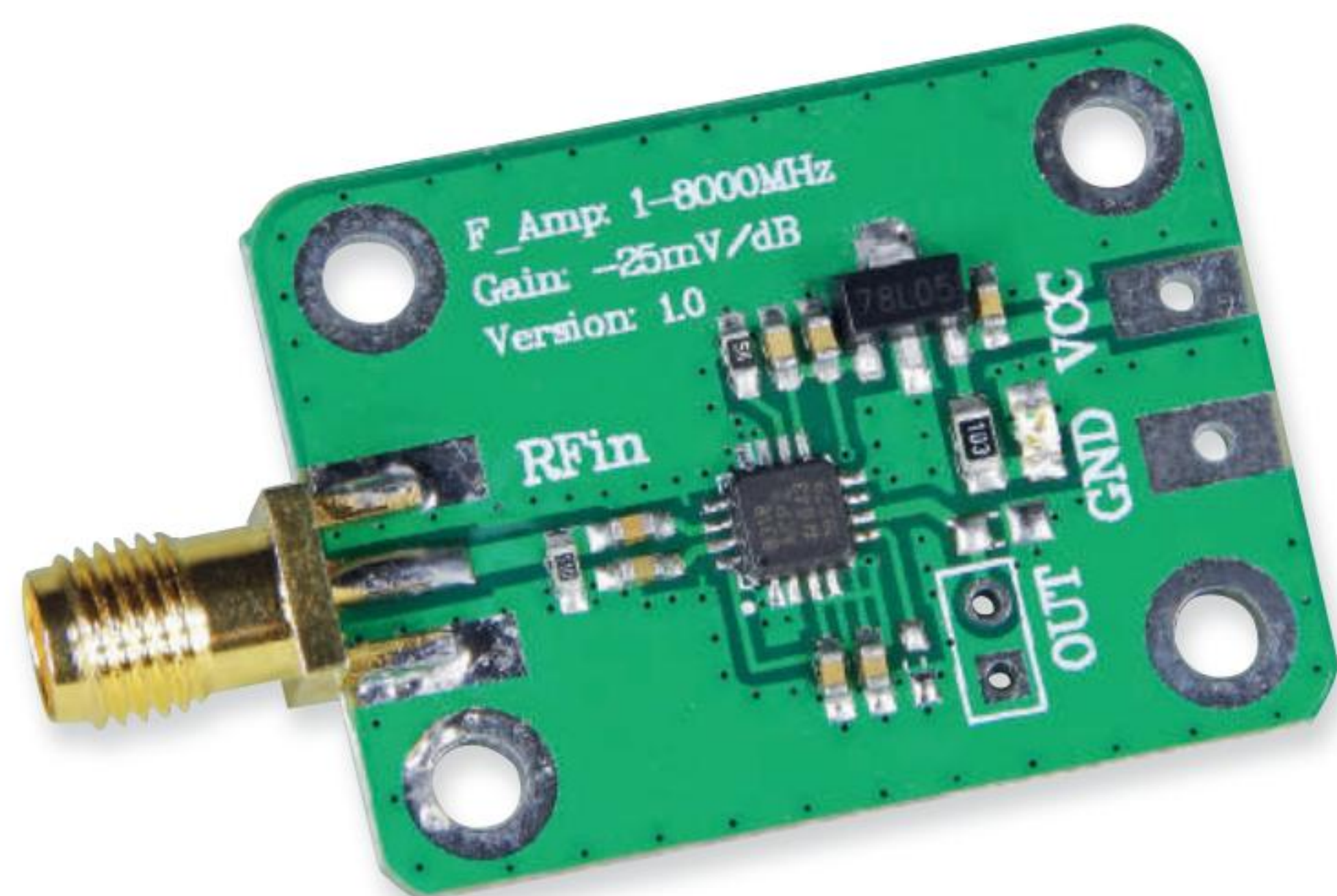
To check out this module, I hooked it up to a suitable 9V DC power supply and connected its RF input up to a VHF/UHF signal generator.

Then I monitored its output using a 4.5-digit bench DMM while varying the RF input level over the range from +10dBm to -70dBm, for four different frequencies: 100MHz, 1GHz, 2GHz and 4GHz.

I wasn't able to go above 4GHz because that's the highest frequency my signal generator provides.

These measurement runs were used to plot the module's transfer characteristic at each of the four sample frequencies and the results are shown in Fig.3. The four plots are very close to linear between RF input levels from -5dBm down to -60dBm, and only curve gently away at the upper and lower extremes.

Although the truly linear part of the module's transfer characteristic only covers about 55dB, the curved sections at each end give it a useful



Banggood's logarithmic *RF Detector* module is based on the Analog Devices AD8318 chip, a logarithmic amplifier/detector IC. It has an RF bandwidth of 1MHz to 8GHz with a range

of -65dBm to +5dBm and an input impedance of 50Ω. The module is very compact – the photos shown here are roughly twice actual size.

range of about 70dB, as claimed in the data sheet.

The linear sections of all four plots are well within $\pm 1\text{dB}$ of each other and have a slope of -24.33mV/dB ; very close to the expected -25mV/dB .

Note that we've mentioned a 60dB range before, as this is the practical range over which you can expect to get an accurate result.

Connecting to Arduino or Micromite

Interfacing this module to a micro is straightforward. Just feed the module with 7.5-9V DC and connect its V_{out} to either one of the micro's own ADC inputs directly, or to a higher-resolution ADC coupled to the micro via an SPI or I²C interface.

After that, it's just a matter of writing a firmware sketch or MMBasic program to read the analog V_{out} signal and convert it into an RF power level measurement.

This module should be suitable for use as the sensor section of a home-brew VHF/UHF level and power meter. You could even use it as an RF sensor head for our Arduino *Multifunction Measuring Shield (MFM)*, although its negative-slope transfer characteristic would require some alterations to the MFM's firmware sketch.

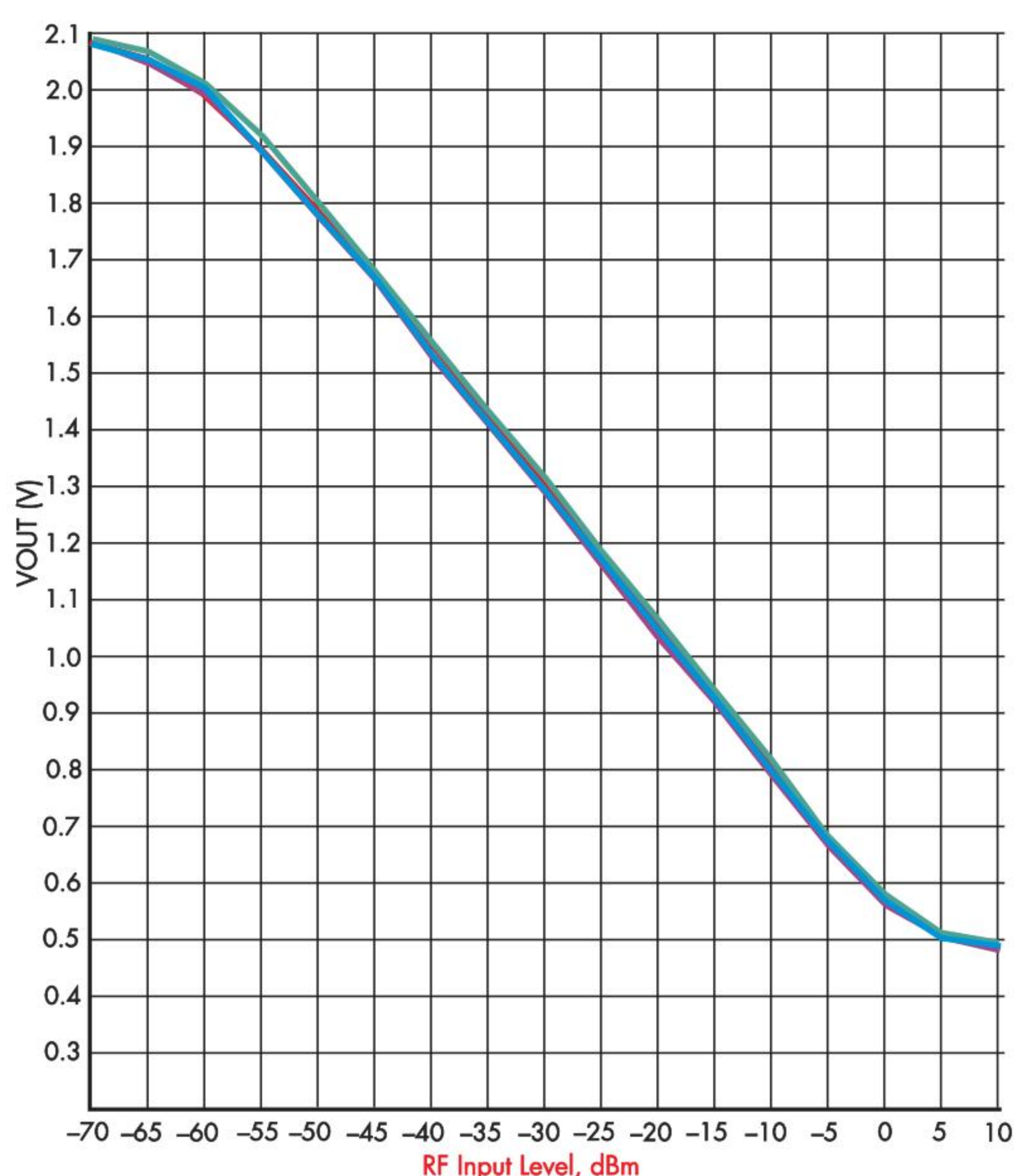


Fig.3: plot of the transfer characteristic for the AD8318 at four different input frequencies. Note the excellent linearity.

RED CURVE = 100MHz
PURPLE CURVE = 1GHz
BLUE CURVE = 2GHz
GREEN CURVE = 4GHz

Other uses would be in an RSSI (received signal strength indicator) for UHF base station receivers and WLAN routers. In short, this *RF Detector* module from Banggood (ID

1119993) seems to represent good value at around £8 including delivery.

Reproduced by arrangement with
SILICON CHIP magazine 2019.
www.siliconchip.com.au

GET THE
LATEST COPY
OF OUR
TEACH-IN SERIES
AVAILABLE
NOW!

ON SALE in WHSmith and other
independent newsagents

PRICE £8.99

(includes P&P to UK if ordered direct from us)

Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

Each part includes a simple but useful practical test gear project that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible, and most of them can be built for less than £10 (including components, enclosure and circuit board).

FREE COVER-MOUNTED CD-ROM

On the free cover-mounted CD-ROM you will find the software for the *PIC n' Mix* series of articles. Plus the full *Teach-In 2* book – *Using PIC Microcontrollers – A practical introduction* – in PDF format. Also included are Microchip's *MPLAB ICD 4 In-Circuit Debugger User's Guide*; *MPLAB PICkit 4 In-Circuit Debugger Quick Start Guide*; and *MPLAB PICkit4 Debugger User's Guide*.

**ORDER YOUR COPY TODAY JUST CALL 01202 880299
OR VISIT www.epemag.com**



MIDI Ultimate Synthesiser



Part 2 | by Paul Cooper | soundtronics.co.uk

Last month, we introduced all the features of the *MIDI Ultimate*, along with a general introduction to analogue synthesis.

This month, we start with the construction of the power supply and sections of the main *MIDI Ultimate* PCB. It is not necessary to comprehensively read through the full circuit descriptions, especially if you are relatively new to electronics, but they can be a useful reference for fault finding. Over the years, I have supported many builders with fault finding their synth projects; and almost without exception, every fault located was due to poor soldering or incorrect component selection/orientation. With care, there is no reason why the synth should not work first time for you as it has for us during the preparation of these articles. A good rule of thumb is to always double check resistor values with your multimeter

because sometimes the colour bands can be difficult to discern under certain lighting conditions. Those of us with aging eyesight use a magnifying glass to read the values on ceramic capacitors and transistors. If you are getting your parts kits from Soundtronics, there is a reference guide to identifying component values included. If sourcing your own components, then here are a few pointers:

- Integrated circuits, transistors and diodes have the manufacturer's code written on them. For example, 'TL072' on an op amp, '2N3904' on a transistor and '1N914' on a diode. Almost all semiconductor components will need inserting the correct way around. Look for a notch or dot on an IC (and the IC socket); the case shape of a transistor; and the band on a diode, which indicates its cathode. The PCB legend will show the correct orientation.

- 25-turn presets are used to set up and calibrate the board. It does not really matter which way around these go; however, the consequence is that you do not know whether to rotate the adjuster screw clockwise or counter-clockwise to (for example) increase the calibration voltage – be prepared for either!
- For potentiometers, the *MIDI Ultimate* uses both linear and logarithmic pots. Linear pots are prefixed with a letter 'B'; log pots have the letter 'A'. The value of the pot in ohms follows the 'A' or 'B' using the convention of a 3-digit code. The first two digits give the first part of the value; the third digit is the multiplier or number of zeros after the first two digits. For example, 'A104' means a log pot with a value of 10 with 4 zeros after, which is 100,000Ω, usually referred to as 100kΩ.



Fig.24. (above) 12VAC, 500mA plug top mains adaptor (wall wart).

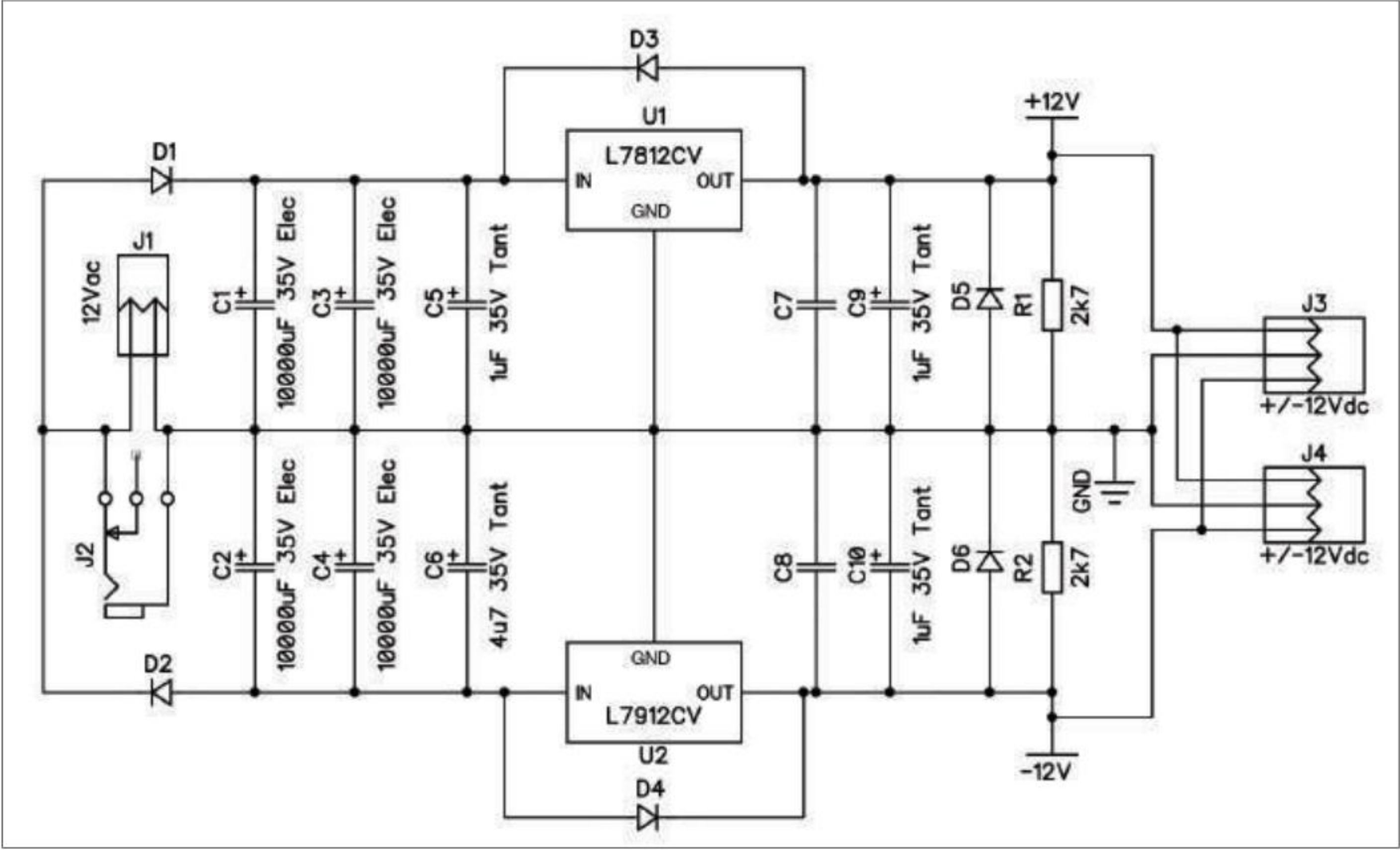


Fig.25. (right) $\pm 12\text{V}$ DC power supply schematic used to regulate the 12VAC from the mains adaptor.

● Electrolytic and tantalum capacitors are straightforward because they have their value and voltage rating printed on their case. Most will also have an indication of the polarity, which is typically a ‘-ve’ band running down one side for electrolytics or a ‘+’ symbol for tantalums. Another indication is that the longer of the two leads is the positive. It is vital that tantalum and electrolytic capacitors are inserted into the PCB the correct way around, as shown on the PCB silk screen.

● Ceramic capacitors have their value in pF (picofarads) printed in a short-hand form, just like the pots described above. The first two digits give the first part of the value, the third digit (on values of 100pF and greater) is the multiplier or number of zeros after the first two digits. For example: ‘102’ means 10 with 2 zeros after which is 1000pF or 1nF. ‘10’ means 10 and as no multiplier is included it is simply 10pF. Finally, ‘224’ means 22 with 4 zeros after which is 220000pF. To further clarify

this, $1,000\text{pF} = 1\text{nF}$ so $220000\text{pF} = 220\text{nF}$, which is how it is referred to in the component lists.

Power supply

The *MIDI Ultimate* requires a power supply unit (PSU) that delivers +12V and -12V at around 300mA. This dual rail supply is derived from a single output 12VAC plug top adaptor or ‘wall wart’. The more common 12V DC adaptors are not suitable for this power supply. Ensure the 12VAC adaptor is rated at 500mA to 1000mA and states ‘AC to AC’.

MIDI Ultimate PSU parts list

Qty	Description	Value	Designator
Resistors			
2	1% 0.25W	2k7	R1, R2
Capacitors			
2	Multilayer ceramic	100n	C7, C8
3	Tantalum	1 μ 35V	C5, C9, C10
1	Tantalum	4 μ 7 35V	C6
4	Snap-in electrolytic	10,000 μ F 35V	C1, C2, C3, C4
Connectors			
1	Truconnect 3.5mm header	10A	J1
1	2.1mm power socket	PCB mount	J2
1	Camdenboss header	CTB9308/3	J3
1	Camdenboss plug	CTB9208/3	J3
Diodes			
6	Rectifier diode	1N4004	D1 to D6
ICs			
1	12V regulator	L7812CV	U1
1	-12V regulator	L7912CV	U2
Miscellaneous			
2	12.5°C/W heatsink	7 x 19.8 x 21.6mm	

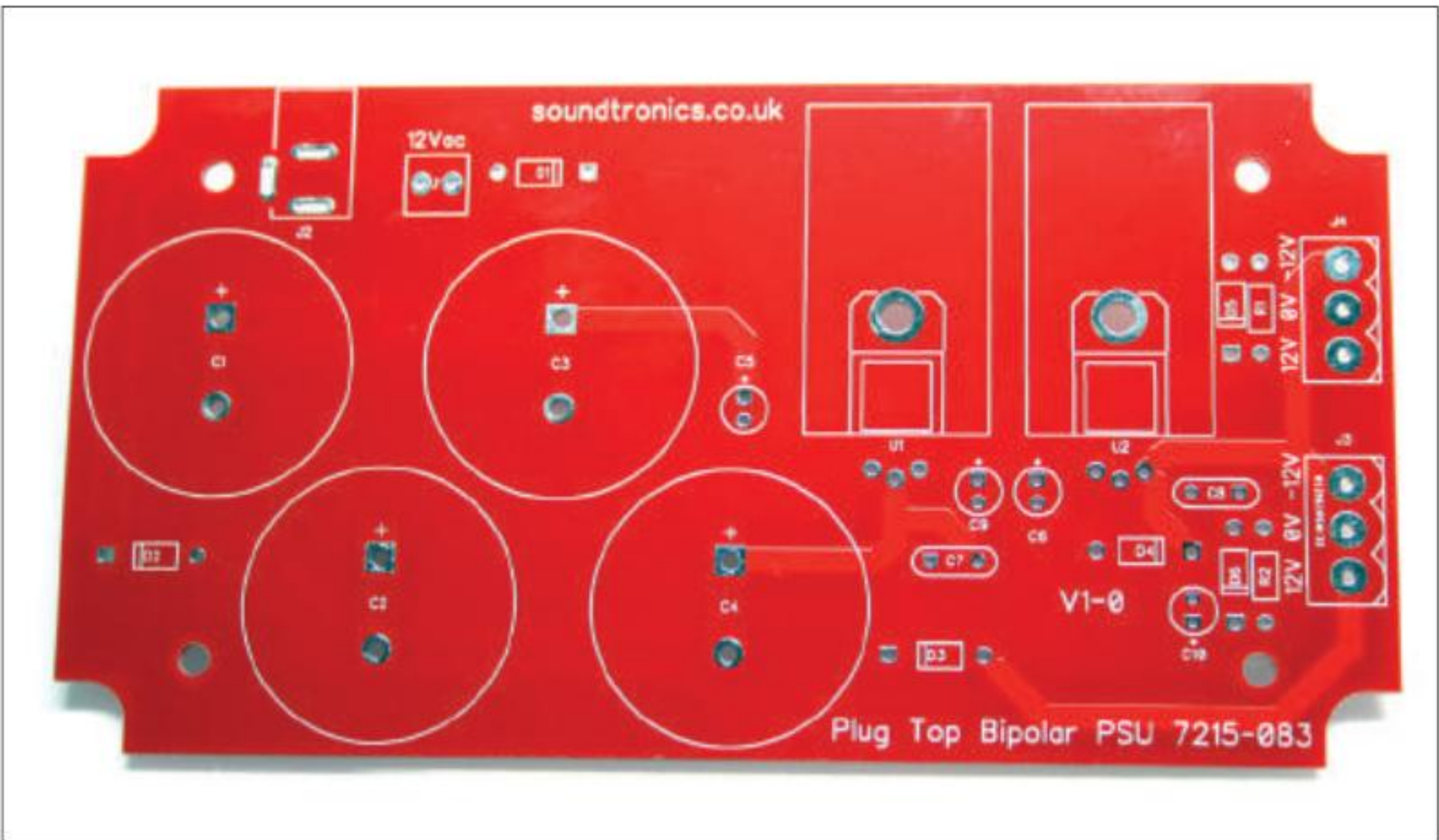


Fig.26. Power supply (PSU) PCB.



Fig.27. Completed PSU PCB in its ABS box that mounts under the *MIDI Ultimate* chassis.

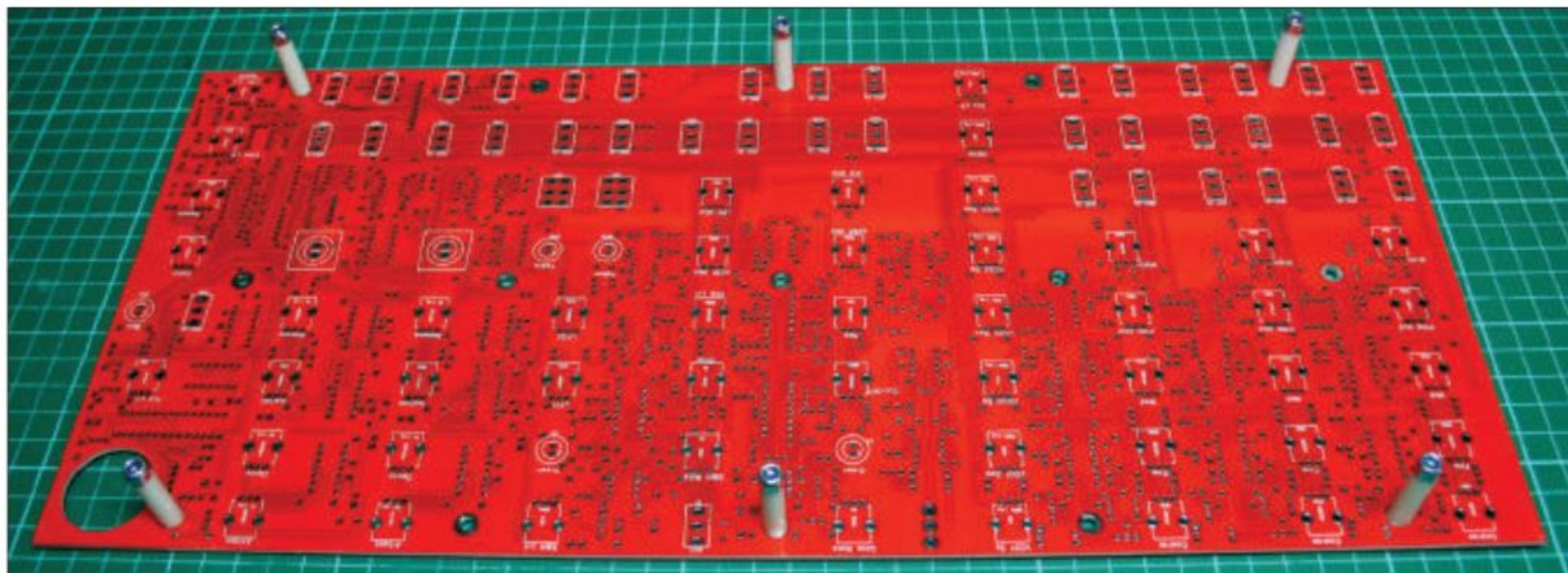


Fig.28. M4 spacers as 'table legs' aid PCB component insertion.

Do note that the circuit designations in the PSU parts list relate to the circuit shown in Fig.25 and should not be confused with those on the main *MIDI Ultimate* PCB. The PSU PCB design has additional flexibility making it a suitable for other projects. The 12VAC input can be via a standard 2.1mm power plug or hardwired direct into a screw terminal block. Two $\pm 12\text{Vdc}$ output connectors are possible, but only one is needed for this synth project.

The PSU is constructed on a PCB (Fig.26) that is available from Soundtronics. The completed power supply will be mounted in an ABS box (Fig.27) that is attached to the underside of the wooden case base plate. This will be described in a later article. For now, the power supply can be used standalone during the build and testing phases.

PSU circuit description

The 12VAC feeds the very conventional voltage regulation circuit based on U1 and U2. Two half-wave rectifier diodes are used: D1 feeds the positive regulator and D2 the negative regulator. C1 to C4 are the main smoothing capacitors, C5 to C10 are provided for decoupling and regulator stability. D3 to D6 are protection diodes to prevent unwanted current paths and any potential regulator latch up. R1 and R2 provide a base load to ensure the regulators give the correct output voltage even when the *MIDI Ultimate* is not connected, enabling you to check for correct PSU operation before first connecting to the synth.

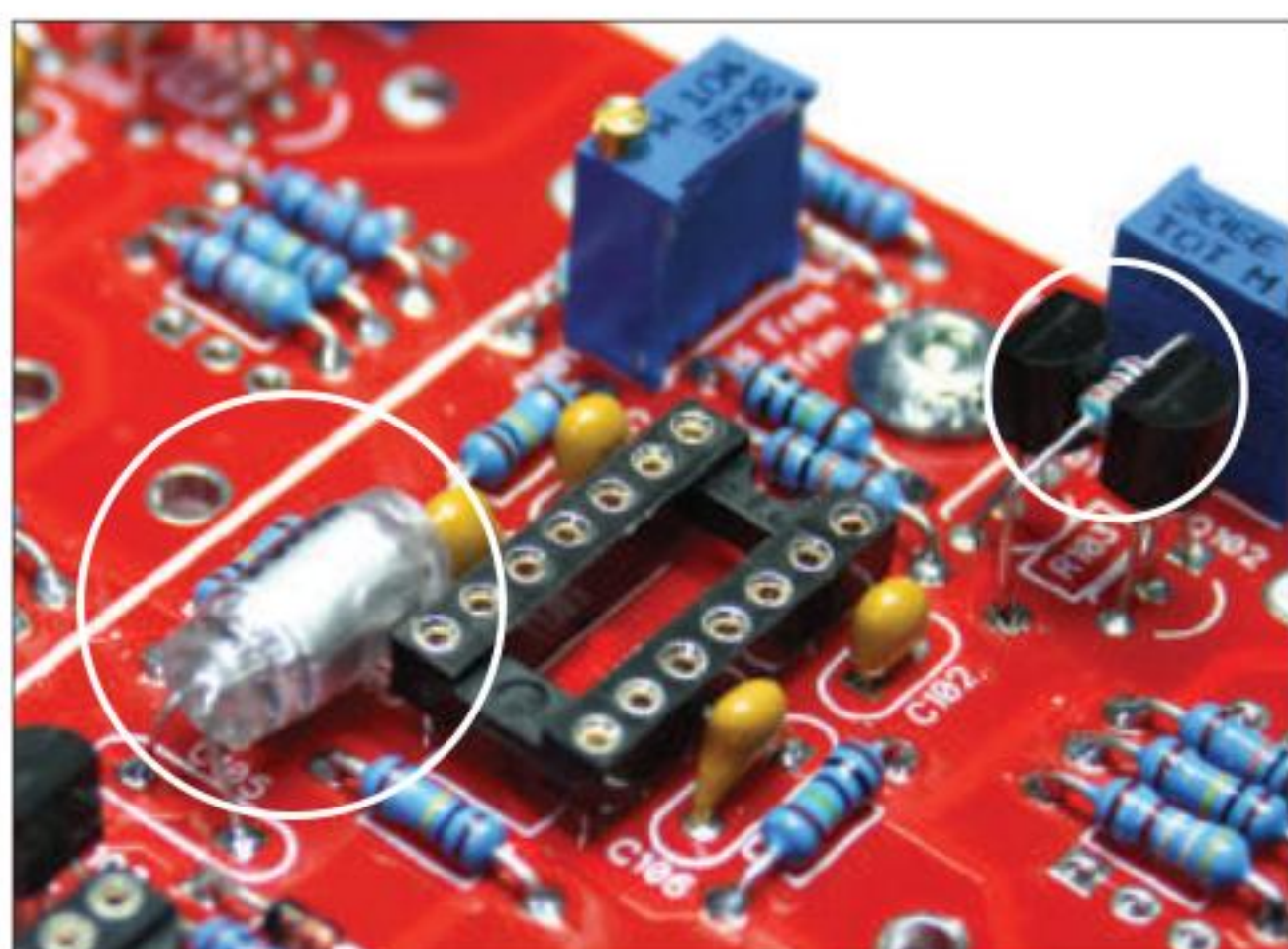


Fig.29. Tempco resistor and polystyrene capacitor locations for the VCOs.

Main PCB construction

The PCB silkscreen shows how the PCB is divided into each of the modules that together form the synth. In this issue, we are populating the components for five sections on the main PCB.

Those of you who are experienced at assembling PCBs no doubt have your own preferred way of undertaking the soldering and this will often depend on the equipment you have to hand. For example, I have a crop and bend machine that can form resistors at the rate of 40,000 per hour, but then I do need to assemble PCBs quickly! I also have a PCB workframe that holds the PCB and allows it to be turned over while holding the components in place. For the purposes of this article, let's assume we only have the most basic of tools to hand.

An important point to note here is that we have components on both sides of the PCB and we are assembling the PCB one or several sections at a time as these articles progress. You may choose to attempt the whole build in one go, but this is not recommended for those less experienced in electronics assembly. So, here are some general tips that you can use to make the PCB assembly that bit easier:

- Use 25mm standoffs on the pot side of the PCB with 30mm M4 screws and lock nuts – these provide the clearance for the component leads and the pots/switches (Fig.28)
- Solder components in ascending height order: resistors, diodes, IC sockets, ceramic capacitors, transistors, trimmer presets, electrolytic capacitors and connectors. Pots and switches are covered later in this article
- Form the resistor leads using small snipe-nose pliers, insert into their corresponding position on the PCB
- Insert resistors in batches of the same value before soldering from the top side; same for diodes
- After soldering the resistors, turn the board over and crop the leads using small side cutters to within 1 to 2mm of the board/joint
- Slightly splay the component legs apart for remaining components so

they do not fall out when turning the board over prior to soldering and cropping

- The turned pin IC sockets are fiddly but need retaining in position with a finger whilst soldering one pin to retain the socket. Double check the IC socket is flat on the board (re-flow the joint if necessary) before soldering the remaining pins. Make sure the socket orientation matches that on the PCB legend indicated by the notch in the outline. Do not insert any chips yet; that comes later.

Start by soldering the resistors for the VCO sections (R1xx, R2xx, R3xx), in batches of the same value, noting that each VCO section is laid out very similar to each other. For example, once you have found the location for R108 in VCO1, you will find R208 and R308 in a similar position in the VCO2 and VCO3 sections. *Do not solder in R103, R203 and R303 at this time!*

Continue with the resistors for the VCF and the mixer, followed by the remaining components as described in the general tips section above. The matched transistor pairs Q101/Q102, Q201/Q202 and Q301/Q302 each require tempco resistors R103, R203 and R303 sandwiched in-between them (Fig.29). Jake Rothman describes a similar arrangement (*Audio Out, EPE*, August 2018) – he also suggests applying heatsink compound between the transistors. For the *MIDI Ultimate*, form the transistor leads so each transistor is in contact with the tempco resistor and a little heatsink compound will not do any harm. The polystyrene capacitors (C105/C205/C305) can be laid over, as in Fig.29. For more on transistor matched pairs, see Jake's article on matching techniques (*Audio Out, EPE*, October 2018).

Your PCB should now look like Fig.30

Pots and switches

Soldering in the pots and switches requires extra care. It is vital they are vertically aligned, otherwise the front panel assembly may not fit. Remove the 25mm standoffs from the PCB for now; they can be refitted when we solder in more components in next month's issue. Insert the pots for the VCOs, VCF and mixer sections, they are a snap-in type so will be retained in position before soldering (Fig.31). The pot values are printed on the PCB so do remember that they are not all the same, you have 10k Ω lin, 100k Ω lin and 100k Ω log being used at this stage.

The switches are mounted to the back panel as shown in Fig.32. Do

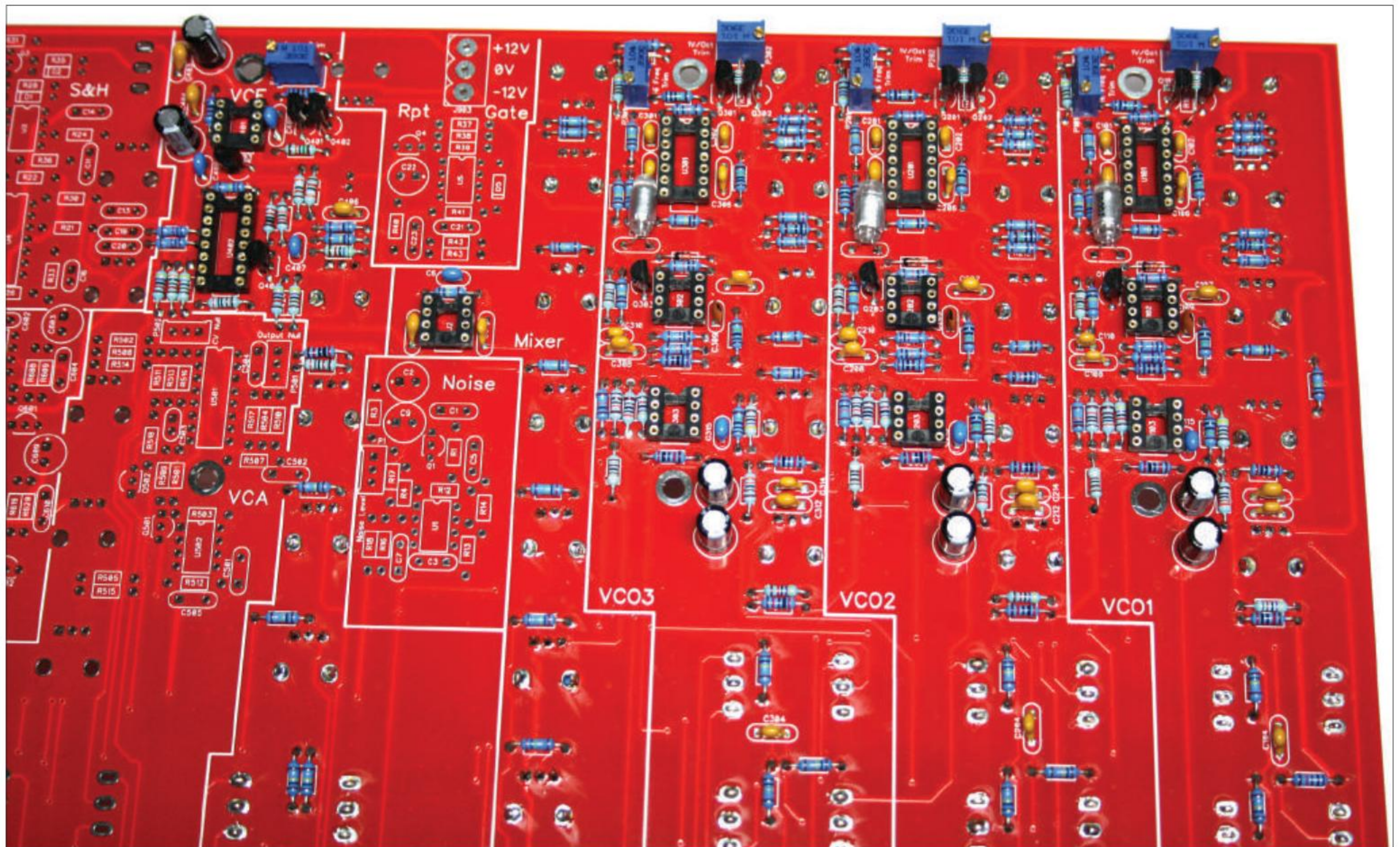


Fig.30. VCOs, VCF and mixer components, pots and switches soldered in place.

not over-tighten the nut. You should still be able to turn the switch bodies so they all align in rows as the switch tags need to correspond with the PCB pads. All switches for the VCOs and VCF are the centre-off type, 22 in total. Screwing in seven M4 × 30mm screws from the front side of the back panel, plus four more, but with 25mm spacers as stand-offs will make the process so much easier (Fig.33).

With the back panel sitting on the table face down on the four stand-offs, slide a 10mm spacer over each of the seven 30mm M4 screws. Now slide the PCB over the seven screws ensuring the pot spindles align with their corresponding panel holes and the toggle switch tags align with the PCB pad holes. It may require a little patience, but it will go.

You should now have the PCB sitting flat on the seven 10mm spacers. These can be locked together with seven more 10mm spacers and M4 nuts, as in Fig.34.

Starting with the pot soldering, ensure the pot is firmly pushed into the PCB and centrally located in the panel hole. The technique we use is to slide a brass 'pen' tube over the pot shaft (available from Amazon and Soundtronics). These have a nominal 50 × 7mm diameter (actually 6.8mm). It is still a bit fiddly, but does do the trick quite nicely. Solder the middle pin first, check alignment, then solder the remaining two pins before soldering the locating lugs. No need to apply too much solder to the lugs, just enough to fill the hole (Fig.36).

Once all of the pots are soldered, move on to the toggle switches. Finally,

remove all the fixings and detach the PCB from the back panel. Before we test what we have built so far, let's describe the VCO, VCF and mixer circuits.

Voltage-controlled oscillators (VCOs)

Before we delve into the circuit description, first some background theory on the Western music scale that expands upon that described by Jake Rothman (*Audio Out*, *EPE*, August 2018). A key aspect is to establish the voltage-frequency relationship because our circuit is a 'voltage-controlled' oscillator. The chromatic scale in music consists of 12 pitches, each a semitone above or below its adjacent pitch; these 12 semitones form an octave. The frequency of each note can be calculated using the equation $f_n = f_o \times a^n$, where:

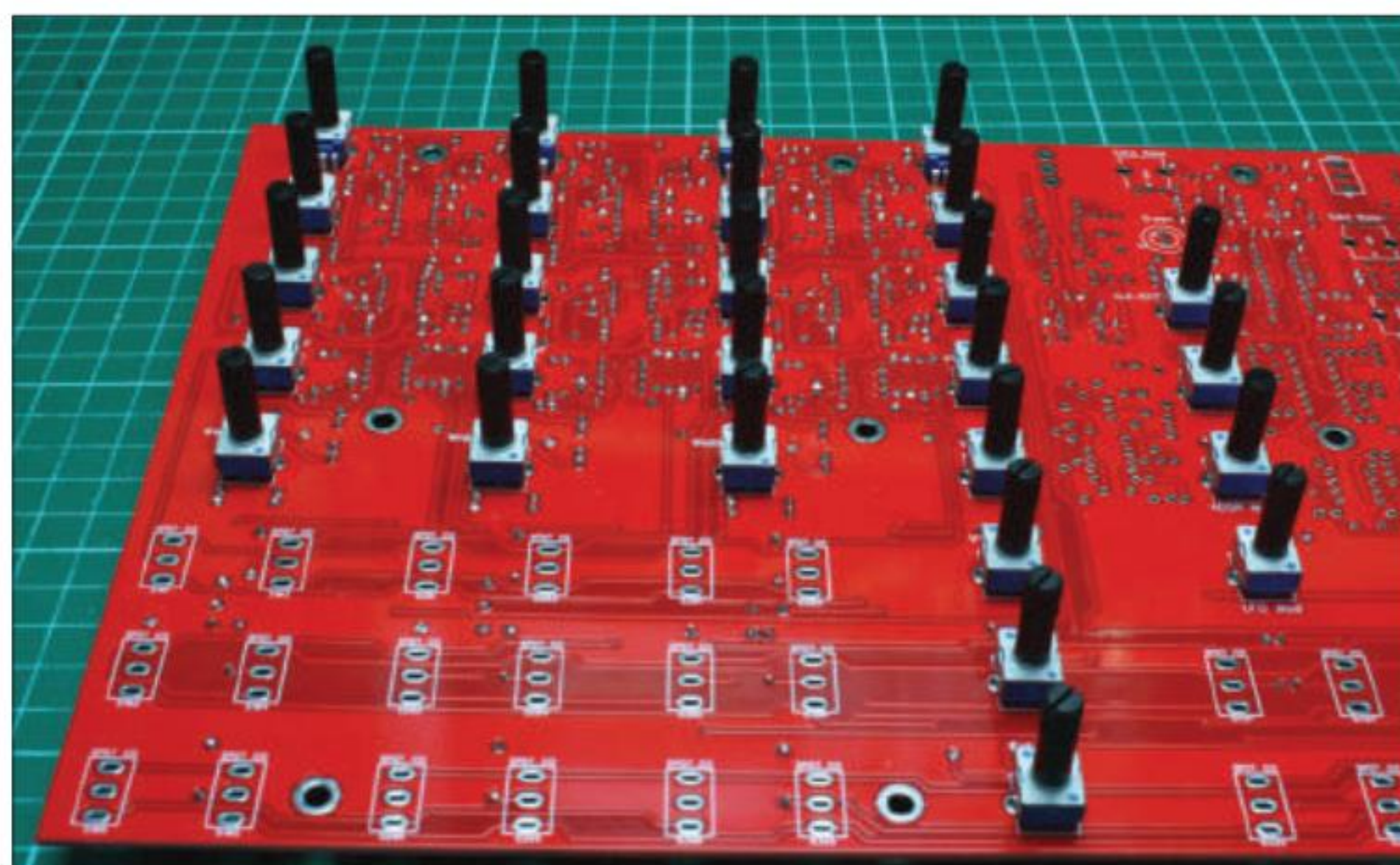


Fig.31. Pots 'snapped' into position in readiness for soldering to the main PCB.

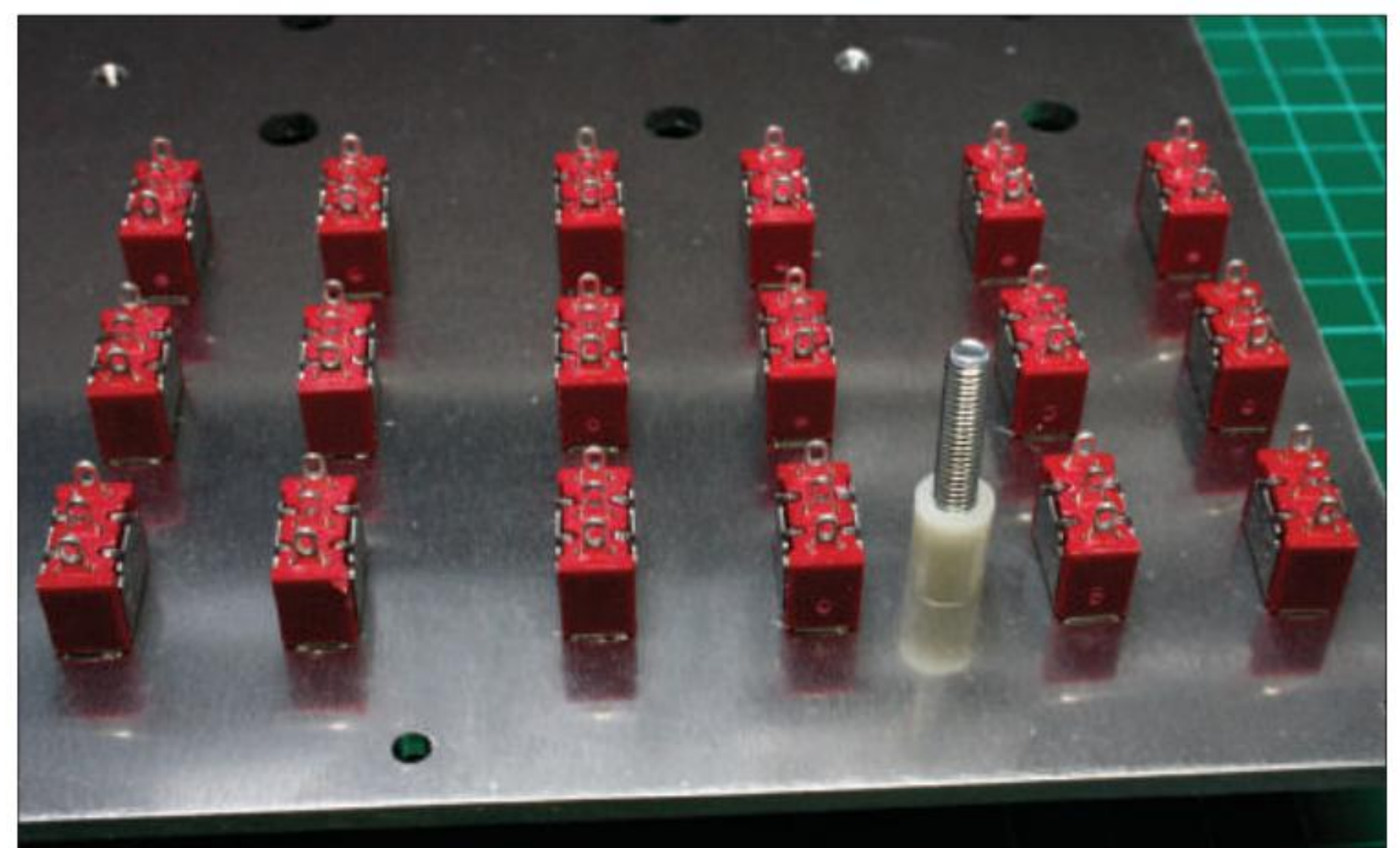


Fig.32. Toggle switches fixed to the back panel prior to the PCB being placed into position.

Note	Frequency (Hz)
A4	440
A#4	466.1637615
B4	493.8833013
C5	523.2511306
C#5	554.365262
D5	587.3295358
D#5	622.2539674
E5	659.2551138
F5	698.4564629
F#5	739.9888454
G5	783.990872
G#5	830.6093952
A5	880
A#5	932.327523
B5	987.7666025
C6	1046.502261
C#6	1108.730524
D6	1174.659072
D#6	1244.507935
E6	1318.510228
F6	1396.912926
F#6	1479.977691
G6	1567.981744
G#6	1661.21879
A6	1760

Table 2: Key/frequency relationship

f_o = the frequency of one fixed note which must be defined. A common choice is setting the A above middle C (A4) at $f_o = 440\text{Hz}$.

n = the number of half steps away from the fixed note you are calculating. If you are at a higher note, n is positive. If you are on a lower note, n is negative.

f_n = the frequency of the note n half steps away.

$a = (2)^{1/12} = 1.059463094359...$ (the twelfth root of 2, that number which when multiplied by itself 12 times equals 2, in other words: $2 = 1.059463094359^{12}$).

The above describes an exponential relationship that results in any note in



Fig.35. Brass ‘pen’ tube used to align the pot shafts.

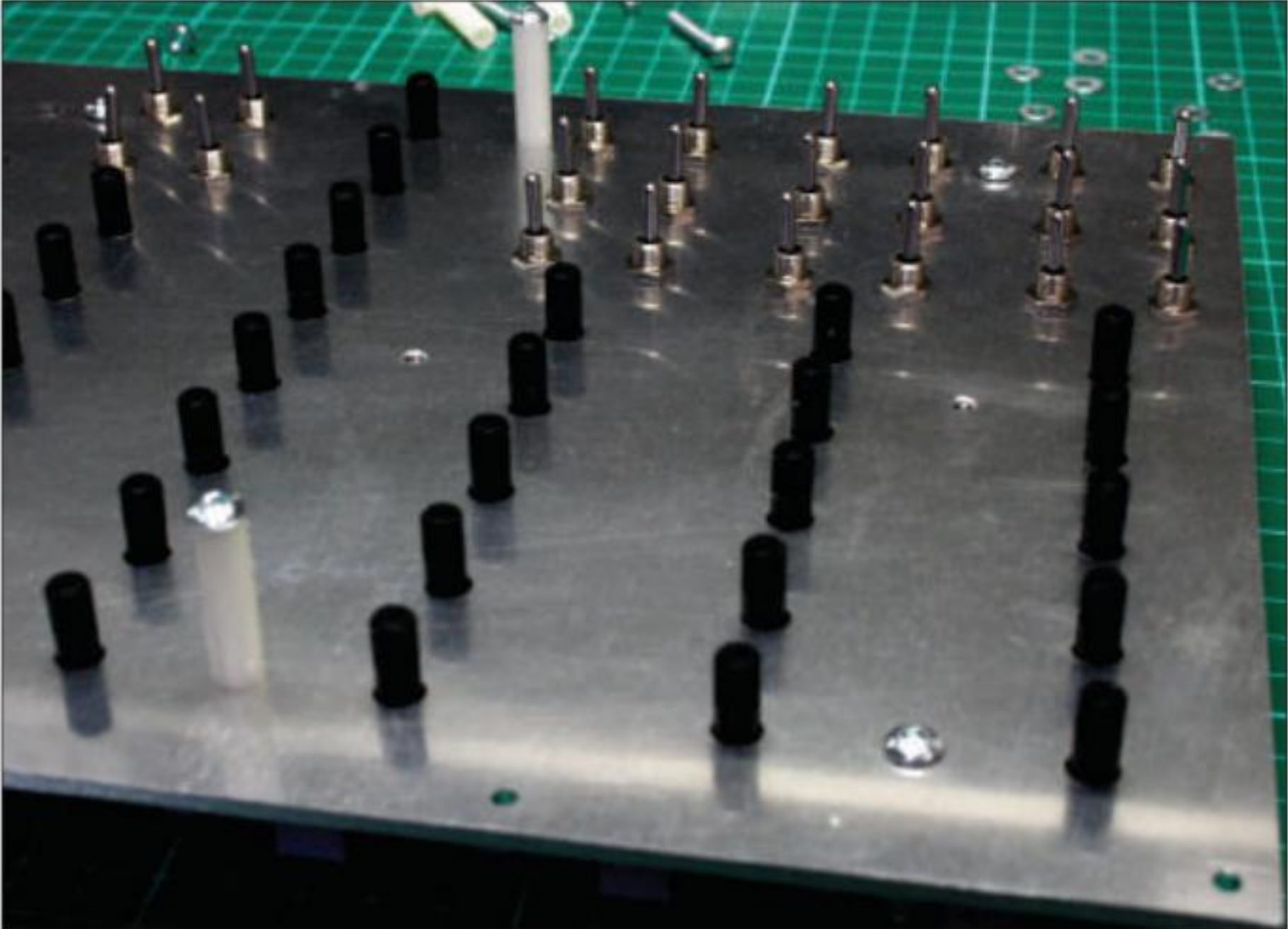


Fig.33. Switches and pots brought together for soldering

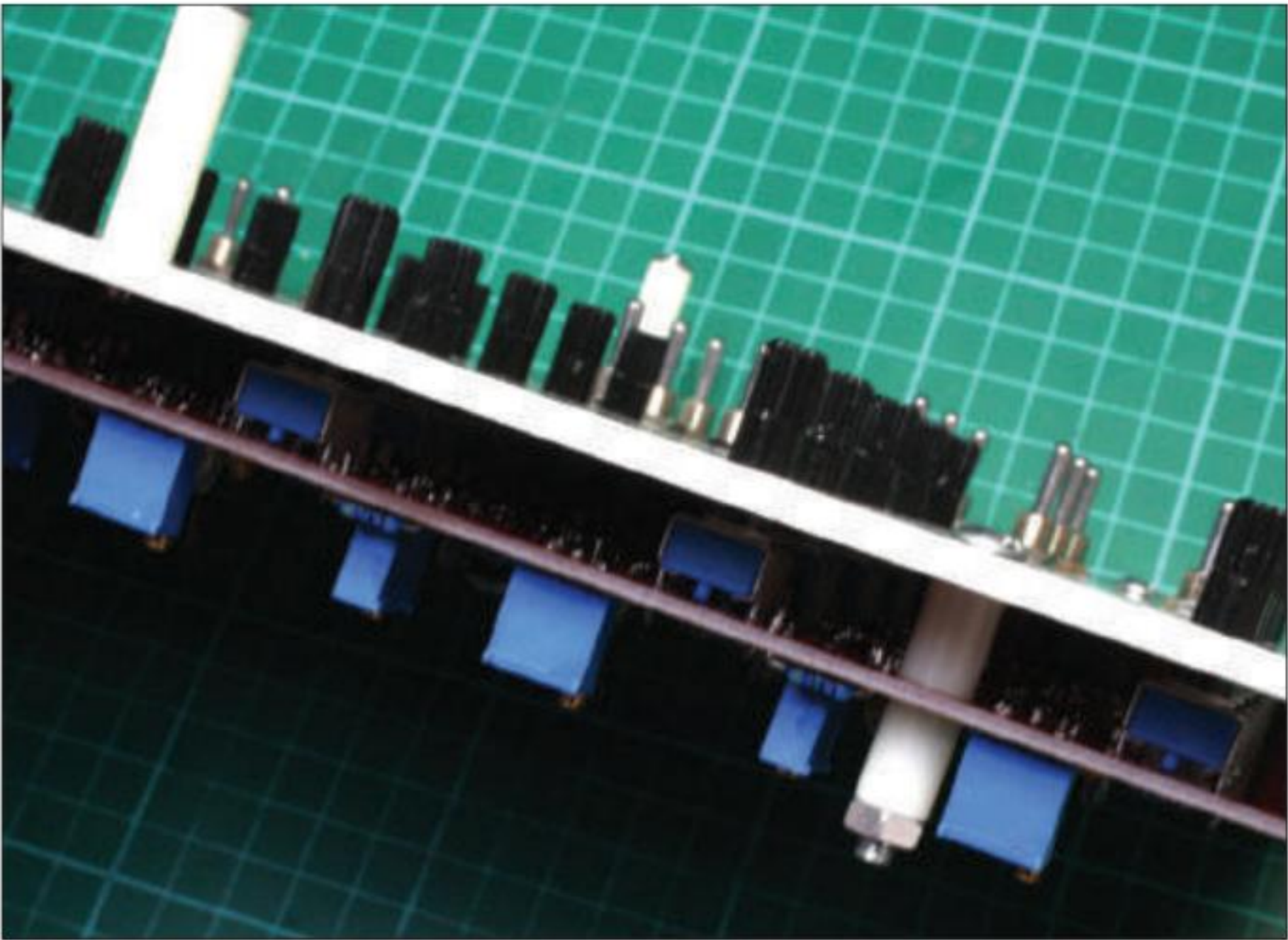


Fig.34. PCB and back panel locked together.

the octave being twice the frequency of the same note an octave below or half the frequency of the same note in the octave above, see examples in Table 2.

For our VCOs, we use a common industry standard of 1V/oct (one volt per octave), which means for every volt increase, the frequency needs to double. This is achieved using a bipolar junction transistor (BJT), which exhibits an exponential relationship between the base-emitter voltage and the collector current.

The VCO (Fig.37) provides over six octaves of excellent in-tune tracking (exponential relationship) and features a sawtooth and variable-width rectangular waveform outputs. These waveforms, in conjunction with low-pass filtering via the VCF, provide a wealth of timbres. The VCOs are of the ramp-core type, where a capacitor is charged until a threshold is reached and then quickly discharged before repeating the cycle again.

VCO circuit description

Four control voltage (CV) inputs determine the frequency of the oscillator. Two of the CV inputs are from the Coarse and Fine Frequency potentiometers (VR101 and VR102 respectively), which provide variable voltage sources. The other two CV inputs are from the frequency

modulation sources via R117 and the main ‘keyboard’ voltage via R101. The Coarse pot provides between about -10V and $+4.5\text{V}$, which is fed via the wiper of VR101 to voltage summer (op amp U101.1) input resistor R107, giving around 14 octaves of adjustment. The Coarse pot will adjust the frequency from a few hertz to about 20kHz . The Fine pot provides between -2.4V and $+2.4\text{V}$, but since it is fed into the voltage summer via R109 ($1\text{M}\Omega$) it only changes the frequency of the oscillator a few semitones from min to max adjustment.

The voltage summer provides a gain of -0.02 for the inputs with $100\text{k}\Omega$ input resistors and -0.002 for the Fine input, which has a $1\text{M}\Omega$ input resistor. Thus, a change of 1V applied to an input with a $100\text{k}\Omega$ input resistor results in a change of -20mV at U101.1’s output. A change of 1V applied to an input with a $1\text{M}\Omega$ input resistor results in a change of -2mV at U101.1’s output. Since the voltage needed to double the current in the linear-voltage-to-exponential-current convertor is about -18mV , P102 provides adjustment to scale U101.1’s output to the correct voltage per volt of input. This trimmer is adjusted later to scale the oscillators to precisely 1V/oct.

U101.4, in conjunction with Q101/Q102 (matched NPN transistor pair) comprises a linear-voltage-to-exponential-current convertor. Transistor Q101 in the feedback loop of U101.4 is responsible for this remarkable effect. In this configuration the voltage applied at the base of transistor Q101 controls the current that flows into the collector of NPN transistor Q102. The relationship of voltage to current is exponential. For every increment of -18mV at the base of transistor Q101, the current flowing into the collector of Q102 doubles in magnitude. The low end of the range of current that this circuit provides starts at about $0.02\mu\text{A}$ when both the coarse and fine pots are turned fully counter-clockwise. When the coarse pot is adjusted to about 40Hz the current is at $0.4\mu\text{A}$ and doubles for every octave thereafter (80Hz $0.8\mu\text{A}$, 160Hz $1.6\mu\text{A}$, 320Hz

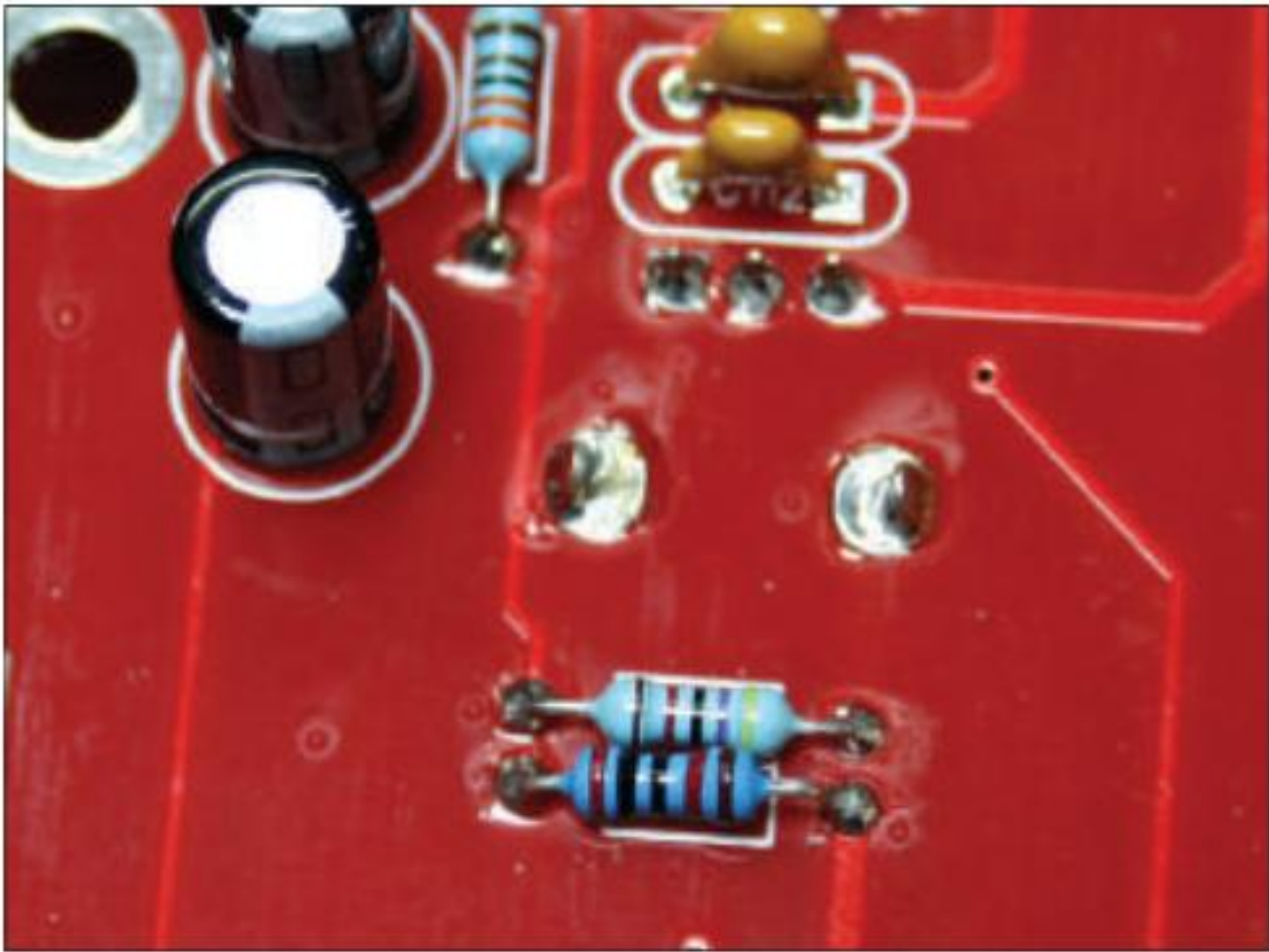


Fig.36. Pots are soldered from the component side (3 pins, 2 lugs).

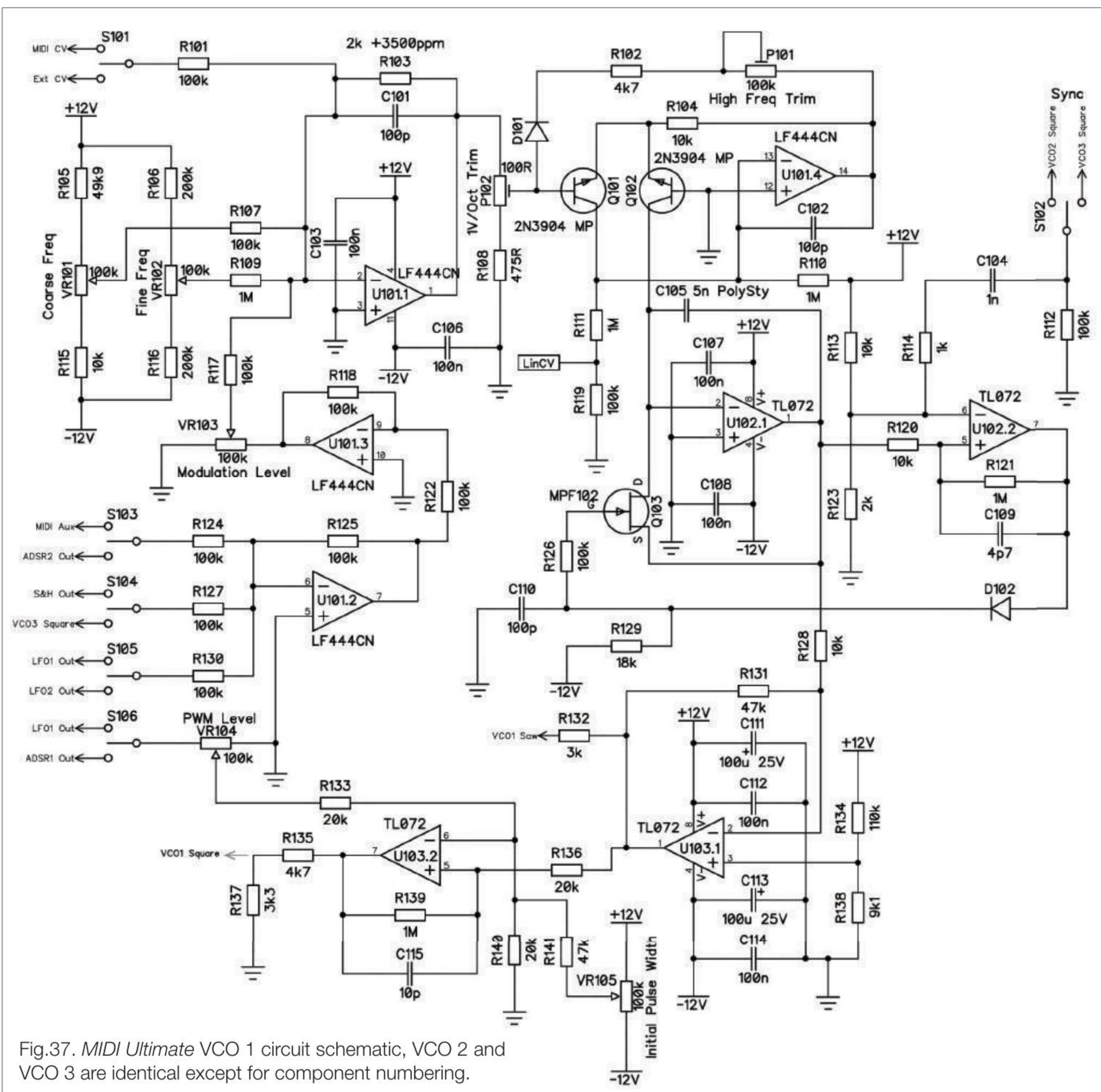


Fig.37. MIDI Ultimate VCO 1 circuit schematic, VCO 2 and VCO 3 are identical except for component numbering.

3.2 μ A, 640Hz 6.4 μ A, 1280Hz 12.8 μ A, 2560Hz 25.6 μ A...). R110 sets the initial current for U101.4's feedback loop (1.2 μ A). C102 stabilises U101.4 since it is not at unity gain. Q101/Q102 need to be V_{be} matched to achieve the widest exponential tracking. Jake Rothman has described the principles for transistor matching (*Audio Out*, *EPE*, October 2018). These transistors need matching to better than 2mV, and Soundtronics can provide ready-matched pairs to typically better than 1mV. V_{be} is very sensitive to temperature changes – typically 2mV/°C. Heat radiating from your hands, warmth from your breath and room temperature fluctuations make the task of matching transistors quite a challenge.

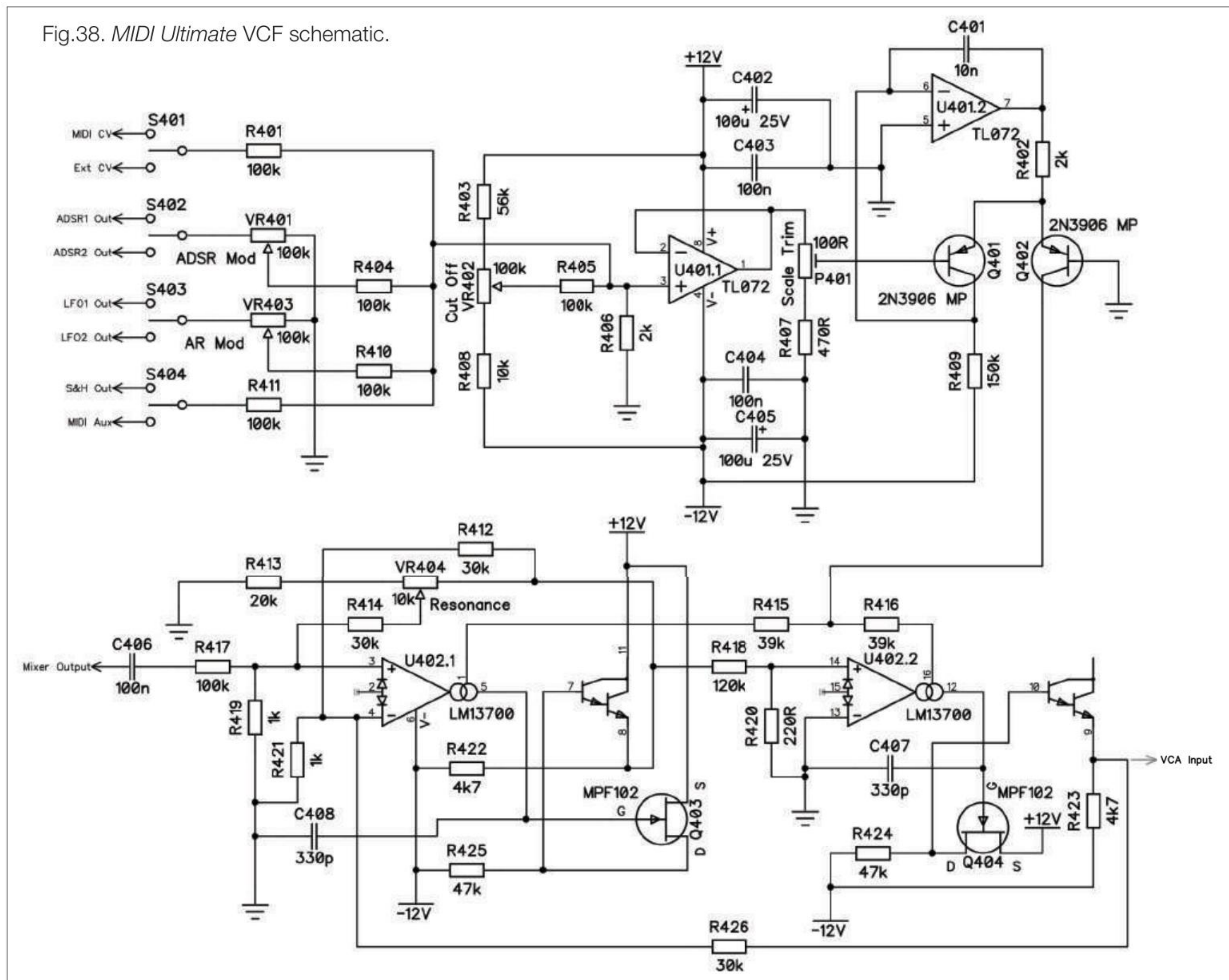
A metal film 2k Ω 0.125W $\pm$ 1% +3300 PPM tempco resistor (R103) is used as

the feedback resistor around voltage summer U101.1. This tempco is used to cancel out the exponential convertor's temperature coefficient. If a metal film resistor is used in its place then the oscillators will drift quite a bit more with temperature changes. D101, R102 and 100k Ω trimmer P101 are used to compensate for the bulk emitter resistance of the base-emitter junction. This resistance causes the oscillator to go flat at higher frequencies. Adjustment of P101 allows this error factor to be compensated so that the oscillator works over a wide range of frequencies.

The current flowing into collector Q102 controls the frequency of the VCO. Op amps U102.1 and U102.2, in conjunction with Q103 MPF102 N-Channel JFET form the heart of the ramp-core oscillator. U102.1 is used as

an integrator in association with polystyrene capacitor C105. Current flowing out of U102.1 pin 2 into collector Q102 causes U102.1's output to rise linearly in voltage. This is because U102.1's output is trying to hold pin 2 at the same potential as pin 3, which is connected to ground. U102.1's output is connected to U102.2, which is wired as a comparator. When the voltage at U102.1 output pin 1 rises above the threshold set by R113 and R123 (slightly above 2V due to the hysteresis provided by R121) U102.2's output (which had been sitting at about -10.5V) shoots to +10.5V. When that happens, Q103's gate is brought high (via D102 and R126) which essentially shorts its drain to source discharging integrator capacitor C105 and resets the integrator's output to ground. Since the voltage on U102.2's non-inverting

Fig.38. MIDI Ultimate VCF schematic.



input is now below the threshold set by R113 and R123, its output returns low (-10.5V) and U102.1's output begins to ramp up again and the cycle continues, resulting in ramp-wave oscillation. C109 conducts the rising output of U102.2 to its non-inverting input (positive feedback) in order to make sure the output snaps high quickly and completely.

The pulse that occurs on the output of U102.2 forward biases D102 and charges 100pF capacitor C110. This charge ensures that Q102 stays on long enough to completely discharge C105. U102.2's output returns low so fast that without this additional charge to keep Q102 on, C105 would not be discharged effectively.

Thus, the output of U102.1 is a ramp wave whose frequency is directly proportional to the current flowing out of U102.1 pin 2. Op amp U103.1 level shifts and inverts the ramp causing it to become a $\pm 5\text{V}$ sawtooth wave oscillating about ground. U103.1's output is fed to the VCO1 sawtooth bus via R132 to protect it from being directly shorted to something it would not like.

The sawtooth waveform is fed to the non-inverting input of U103.2 wired as a comparator via R136. When the sawtooth is above the voltage seen at U103.2 pin 6 (plus a bit of hysteresis due to R139) the output of U103.2 goes high. When the sawtooth is below the voltage seen at U103.2 pin 6 (plus a bit of hysteresis due to R139) the output of U103.2 goes low. Pulse-width adjustment pot VR105 sets the voltage level on U103.2 pin 6 (via R141) and thus changes the duty cycle of the rectangular pulse appearing on U103.2's output. Pulse-width modulation from LFO1 or ADSR1 is via attenuator pot VR104 and R133. R135 and R137 reduce the amplitude of the rectangle wave to $\pm 5\text{V}$ and R135 doubles as U103.2's output-protection resistor to protect it from

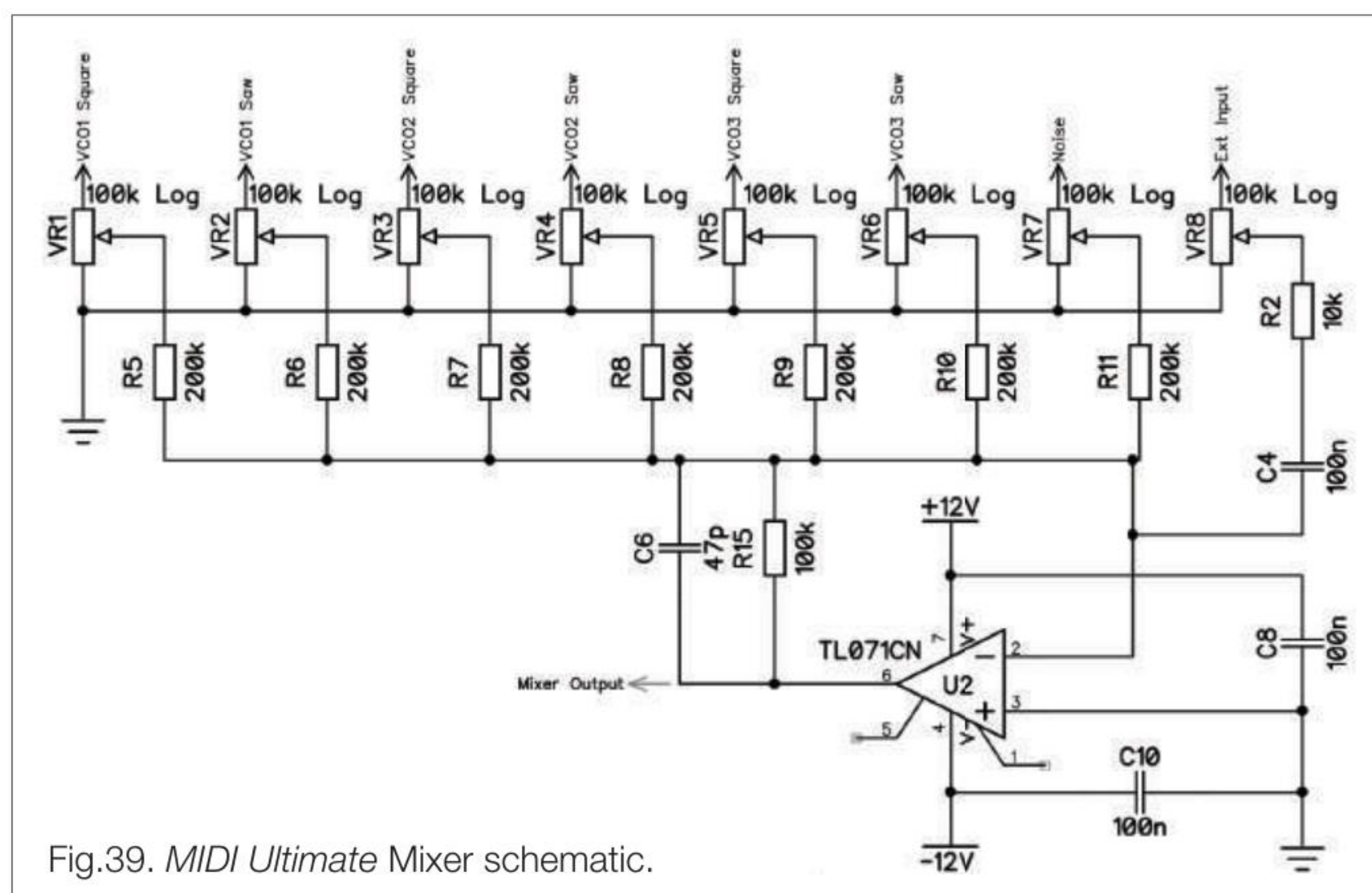


Fig.39. MIDI Ultimate Mixer schematic.

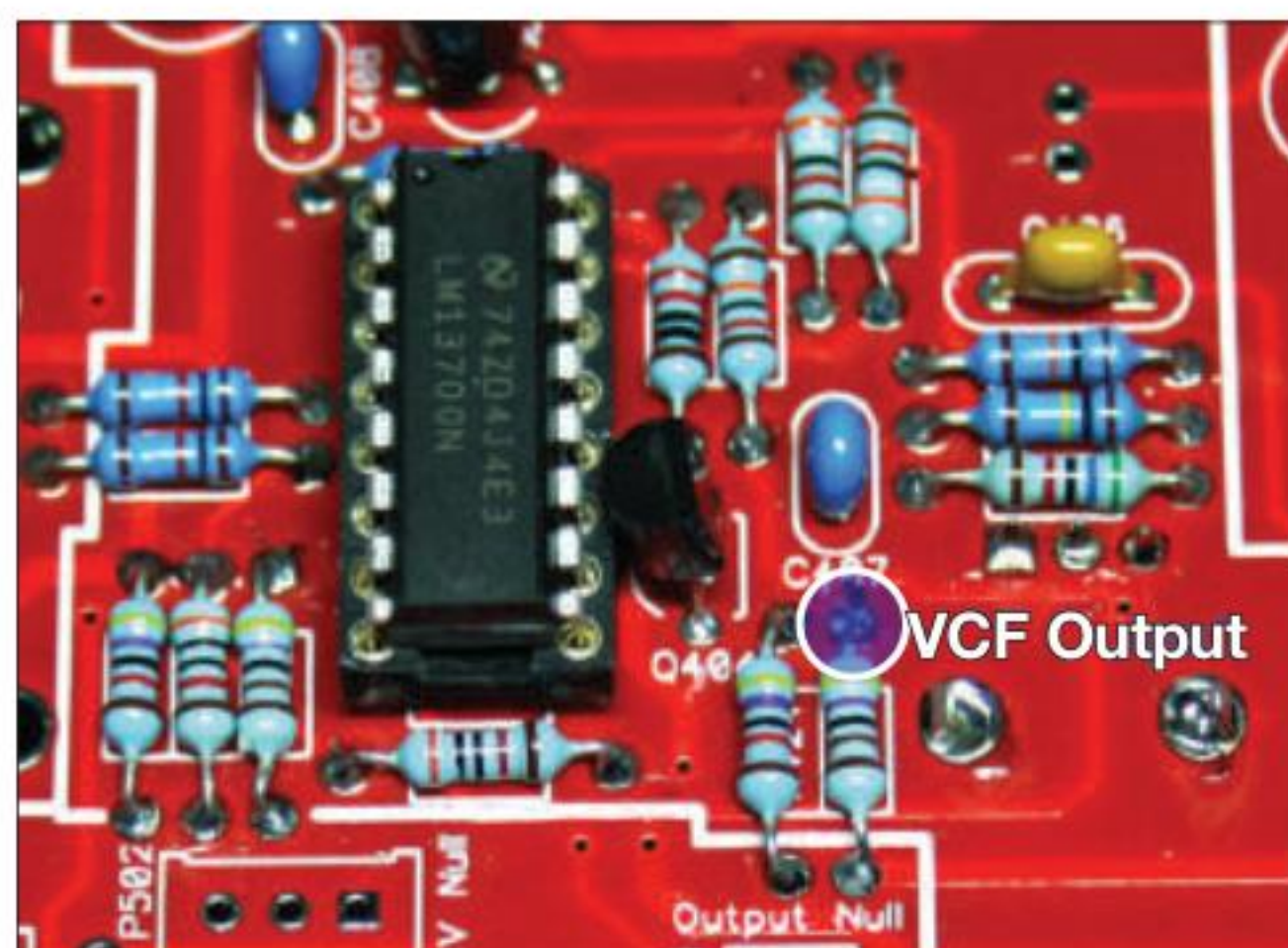


Fig.40. VCF output test point.

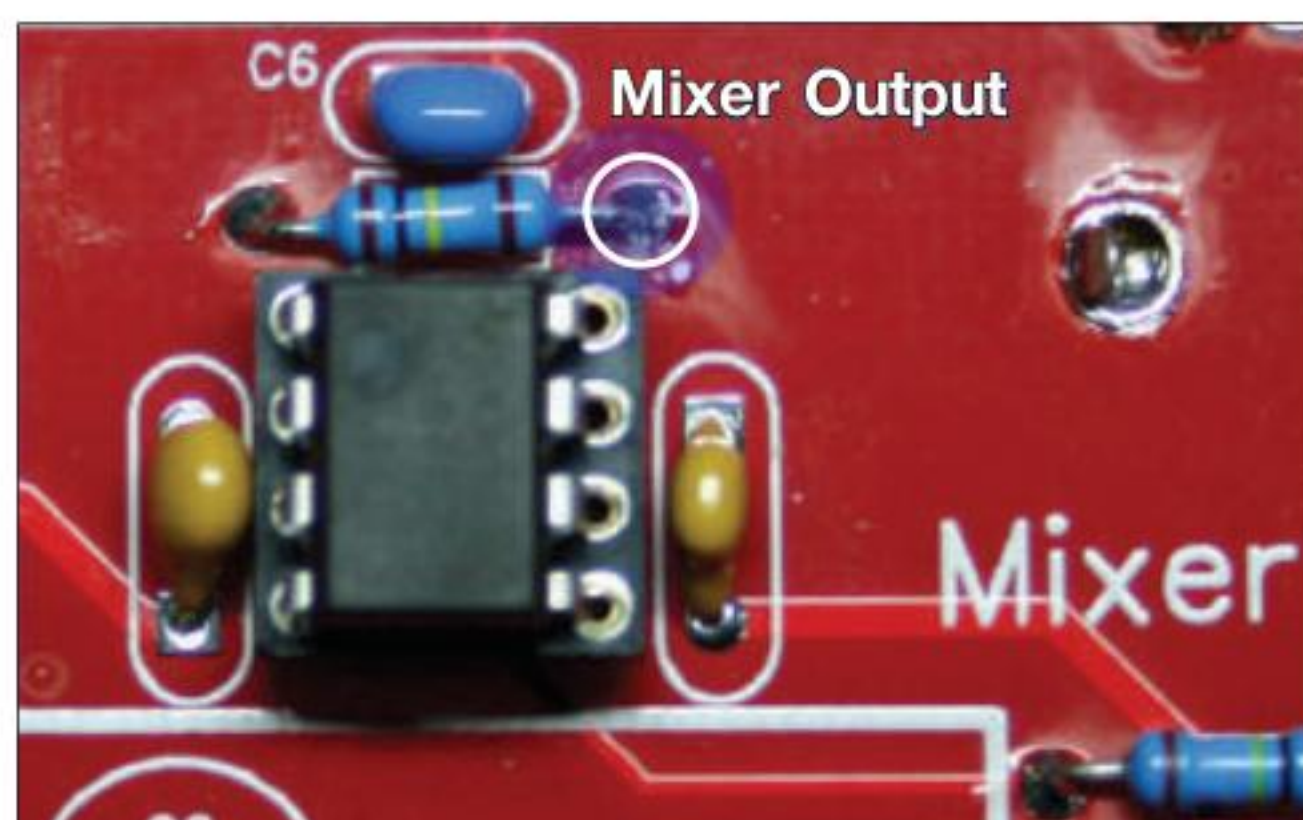


Fig.41. Mixer output test point.

being directly shorted to ground. C115 sharpens up the rectangular waveform by applying positive feedback for the edge of the output back to the non-inverting input.

The sync input from the outputs of the other two VCOs permits another oscillator to cause this oscillator to reset prematurely. The other oscillator must provide a hard edge to effectively sync this oscillator (rectangular, saw or ramp). When the other (sync source) oscillator is oscillating at a lower frequency than this oscillator and this oscillator is swept low to high a distinctive timbre is produced.

Frequency modulation of the VCO can be routed from three pairs of sources: the LFOs, ADSR2/MIDI aux, and S&H/VCO3. Each of these pairs is summed using inverting op amp U101.2 and inverted through U101.3 to restore the original polarity. The combined level of modulation is set using pot VR103.

Voltage-controlled low-pass filter

This VCF (Fig.38) is a low-pass filter that provides plenty of resonance up to and including being a decent sine-wave oscillator when the resonance control is advanced toward maximum.

Like the VCOs, the VCF also requires an exponential frequency cut-off point response so the filter can, for example, track the VCOs to maintain a similar harmonic content irrespective of what note on the keyboard is played. The control-voltage mixer and voltage-to-exponential current convertor is built around U401.1 and U401.2. The control-voltage mixer is non-inverting and mixes the CV inputs from five sets of control-voltage sources:

- Manual cut-off pot set by VR402
- Main MIDI / external CV tracking via R401
- S&H/MIDI auxiliary via R411
- LFO1/LFO2 via attenuation pot VR403
- ADSR1/ADSR2 via attenuation pot VR401.

No attenuation pots have been provided for the MIDI auxiliary or S&H as these sources have their own integral attenuation pots.

Each control voltage source is mixed via 100k Ω resistors onto a 2k Ω resistor to ground (R406). This is a passive mixer, but the 50 to 1 ratio of input resistor value to ground node resistor value is high enough that there is little interaction between the control voltage inputs.

This op-amp-saving design yields impressive results. The output of U401.1 is adjustable via trimmer P401, and thus the voltage can be scaled to +18mV per volt of control voltage input. Since the LM13700 U402 requires positive current to flow into its amp bias inputs, PNP transistors are used in the linear-voltage-to-exponential-current convertor. The control voltage mixer (U401.1) supplies +18mV per 1V increase of control voltage (after trimming P401). For every increase of 18mV applied to the base of Q401 there is a doubling in the magnitude of current flowing from the collector of Q402 into the amp bias inputs (via current limiter/splitters R415 and R416). Just as with the VCO exponential-convertor transistors, making Q401 and Q402 V_{be} matched pairs gives the best possible tracking.

The two halves of U402 (LM13700 dual transconductance amplifier) are used as voltage-controlled integrators in the filter circuit. This is an improvement on the state-variable filter design found in the National Semiconductor data sheet, *LM13700/LM13700A Dual Operational Transconductance Amplifiers with Linearizing Diodes and*

Buffers (November 1994, figure 14). Source followers (Q403 and Q404) are added to the circuit to increase the impedance of the amplifiers that follow the integrators (U402.1 and U402.2). This results in more accurate integration and the ability to oscillate when the Resonance control is advanced toward its maximum level.

Mixer

This is a simple 8-channel active mixer (Fig.39) built around the U2 TL071 low-noise op amp. It provides adjustable levels for the three VCO sawtooth and pulse waveforms, the noise source, and the external input. The synth VCO / noise signal inputs are amplified with a gain of 0.5 because they are fed in via 200k Ω resistors and the mixer's op amp (U2) has a feedback resistor R15 of 100k Ω . The external input has the potential for a gain of 10 when the pot is turned completely up because its input resistor R2 is 10k Ω . So the external signal source should have a level of around ± 500 -600mV.

The advantage of an active mixer is that the input node (pin 2 of U2) is a virtual ground. Thus the inputs act more independently because there is very little to no interaction between the volume level settings. This is an inverting mixer.

If you are familiar with op amp operation then you know you can, of course, pick other values for the oscillator and noise input mixing resistors (R2, and R5 to R11) as well as the op amp's feedback resistor R15 so that the mixer can give more gain to the external input or white noise if you want it to. For example, if all of these resistors (R5 to R11 and R15) were multiplied in value by 10 (2M Ω for the 200k Ω resistors and 1M Ω for the 100k Ω feedback resistor) then the external input would have the potential for a gain of 100, which may be more useful for, say an electric guitar.

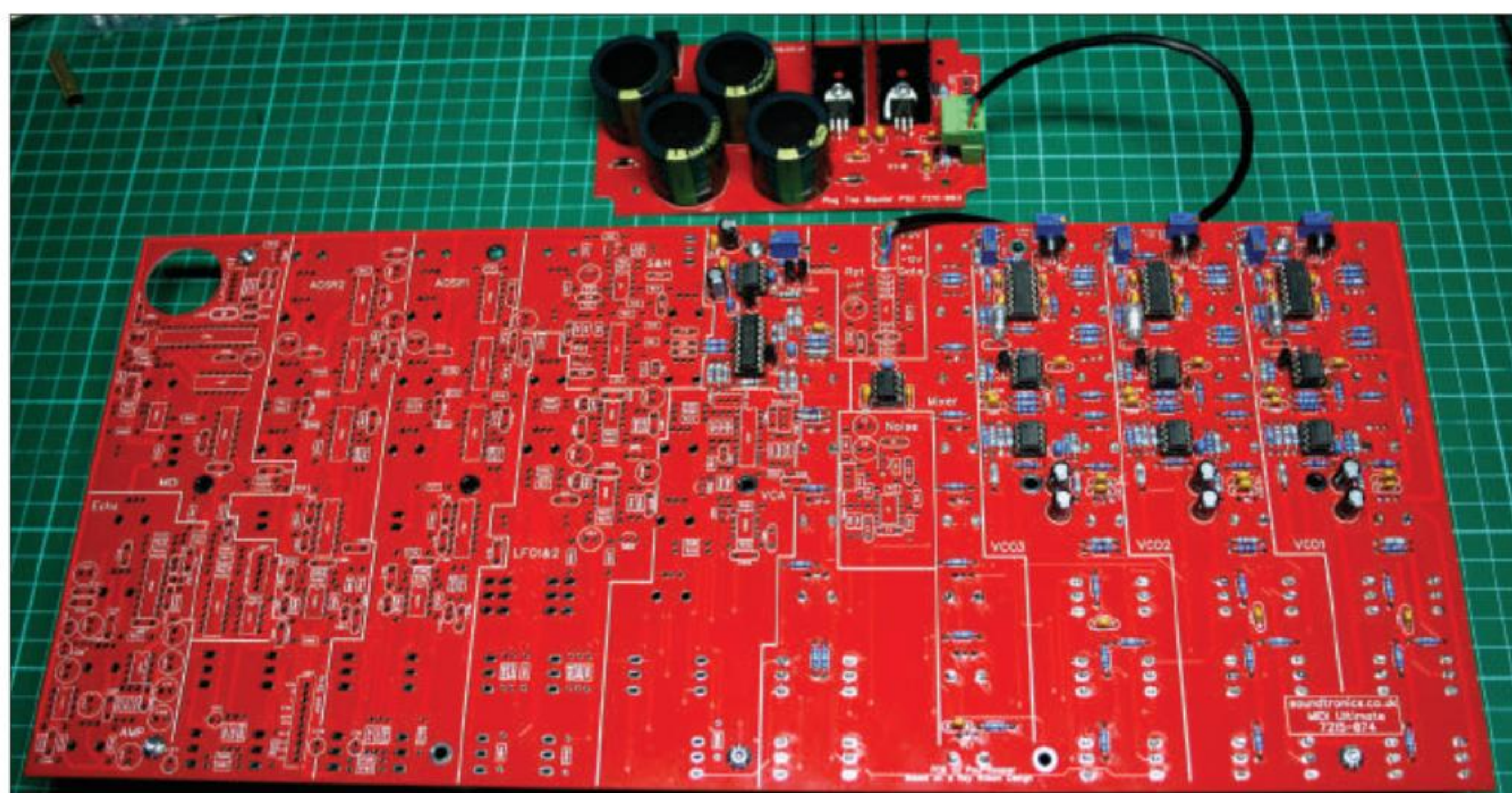


Fig.42. PSU and main PCB ready for testing.

C6 stabilises the operation of op amp U2. Op amps are generally compensated for unity gain and when the gain is higher or lower than that, adding the compensation capacitor is a good measure.

Testing

Before we commence testing, re-fit the six stand-offs, as shown in Fig.28. This this keeps the PCB off the table and reduces the chance of short circuits from stray copper wire left on your table after cleaning up!

First, test your PSU, plug in the 12VAC mains adaptor and check for $\pm 12V$ at the output connector.

Next, using a short length of 3-core cable or three lengths of 7/0.2mm stranded wire, connect the plug to one end of the cable and solder the other ends into the main PCB. We use red for +12V, green for 0V and blue for -12V. Before inserting any of the chips into the main PCB, plug in the PSU connectors and check for $\pm 12V$ at the main PCB. Any wrong polarity on the power supply will cause damage to components, so double check your wiring before applying power for the first time. Unplug J3 and proceed with inserting the chips as in Fig.42. (With such large smoothing capacitors, switching off the PSU could leave a voltage on the main PCB due to the long discharge time, which is why you should disconnect the supply.) Now plug J3 back in and ensure the PSU is energised, check again for $\pm 12V$ at the main PCB.

If you have an oscilloscope, testing is straightforward, but if you don't, see the PC-based scope section below and then return to this section. First, ensure J3 is unplugged. There are two main test points, the VCF output at the top of R423 (Fig.40) and the mixer output, right-hand end of R15 (Fig.41). You can clip a scope lead on these resistors or solder a short length of wire to the particular resistor pad and attach your scope lead to that.

Rotate all pots fully anticlockwise, and then rotate the coarse frequency controls on the VCOs to their mid-point and the same for the VCF cut-off point. The pot descriptions are silk-screen printed on the PCB, making their identification easy.

With the scope attached to the VCF output, plug in J3 and observe the output. Increase the resonance control and when it is near its maximum, you should see a sinewave. With the resonance control fully clockwise, adjust the VCF cut-off point and you will see the sinewave frequency change. Leave the cut-off point fully clockwise and the resonance fully anticlockwise.

Now move the scope to the mixer output, turn the VCO1 square-wave mixer pot to maximum and you should see a pulse waveform. Varying the VCO1 width pot will alter the pulse-width ratio and altering VCO1 coarse pot will alter the frequency. Turn VCO1 square-wave mixer pot fully anticlockwise and repeat this test for VCO 2 and 3 with their respective mixer pots. For completeness, check the sawtooth outputs for each VCO in a similar manner. We'll leave the calibration of the VCOs and VCF

until we have the MIDI interface built.

Finally, with just the VCO1 mixer pot turned clockwise, return the scope to the VCF output where you should observe a rounded off square wave. Turn the VCF cut-off pot anticlockwise and eventually the square wave will become a sinewave.

Next issue

Next month, we will add the VCA, echo, noise and headphone amplifier to the *MIDI Synthesiser*.

PC-based soundcard oscilloscope

If you do not have an oscilloscope, then an alternative is to use the soundcard on your PC with a basic scope software package. This has the benefit of you being able to hear the sound as well as see it. Suitable software can be downloaded from: www.zeitnitz.eu/scope_en and is free for not-for-profit individuals. The waveform screenshots in last month's issue were all captured from the Zeitnitz software.

The 3.5mm stereo jack line input on your PC soundcard is limited to around 1V which is fine when plugging into the line output socket of the synth, but not if we are making measurements directly on the PCB. The solution is to make up a two-part test lead with an integral

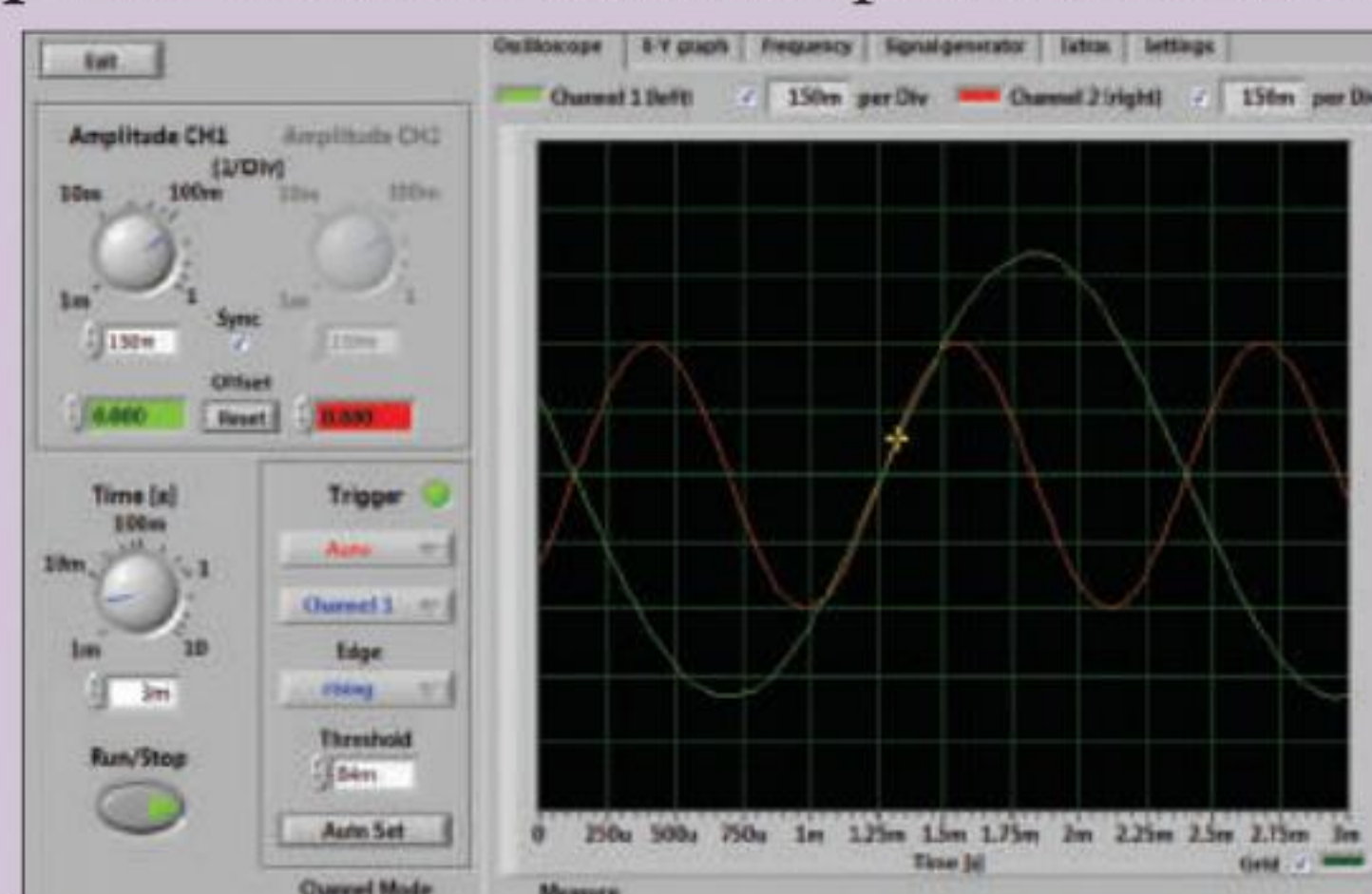


Fig.43. Zeitnitz Sound card scope software.

signal-level attenuator. The first part is a 3.5mm stereo jack plug to a 1/4-inch mono jack plug lead. The second part has a 1/4-inch inline jack socket on one end and test clips on the other (Fig.44). The attenuator consists of two resistors (820k Ω /91k Ω) forming a potential divider soldered in the 1/4-inch jack plug to attenuate the signal by a factor of 10. The scope software can compensate for this reduction under the 'settings' tab by entering a 'Calibration of amplitude' of 10V/Div – don't expect fantastic accuracy, but it will be indicative of waveform shapes, which is what we are most interested in.

To make the leads, take a 3.5mm stereo jack-plug-to-plug lead – the type that often comes with PCs or PC speakers, and cut off one of the jack plugs. At the cut end, solder on a 1/4-inch jack plug along with the 820k Ω /91k Ω resistors. Either of the two core conductor wires can be used, but cut back the other – the only difference is which channel the scope displays on. The second part of the lead is based on a 'dual hook clip oscilloscope test probe' available from eBay. Cut off the BNC end and soldering on a 1/4-inch inline jack socket – you are now ready to go (Fig.45). The testing this month requires both parts of the lead plugged together but in later issues, we will be able to plug directly into the line out socket on the rear of the synth.

That is the testing complete for this month, you can wire the VCF output to the line input of an amplifier (or soundcard using the lead described above) and try mixing different waveforms with various VCF resonance and cut-off point settings. Share photos of your build on SoundtronicsUK Facebook page where you can also post any support questions.



Fig.44. Scope leads with clips/jack plugs.

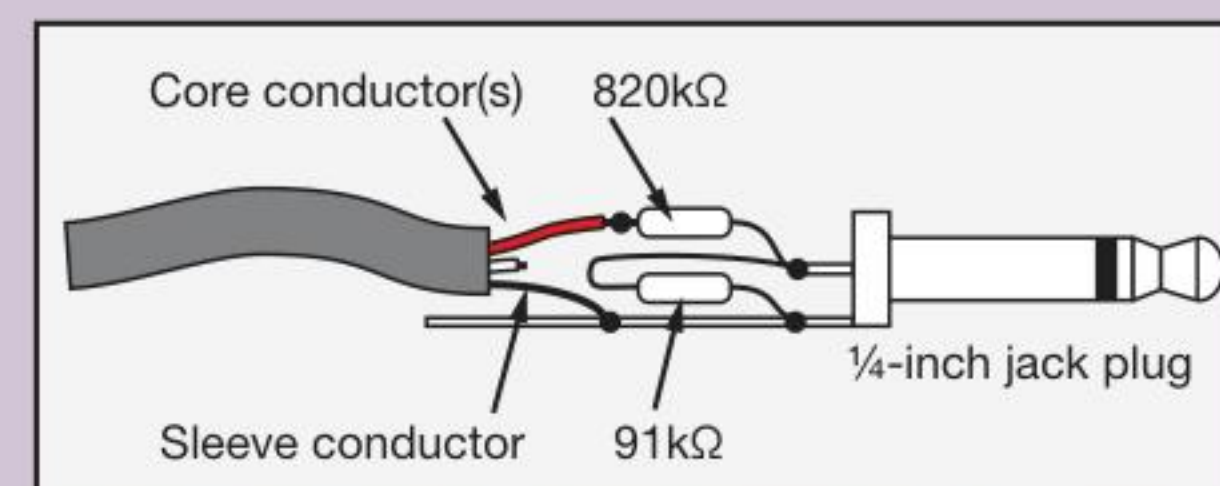


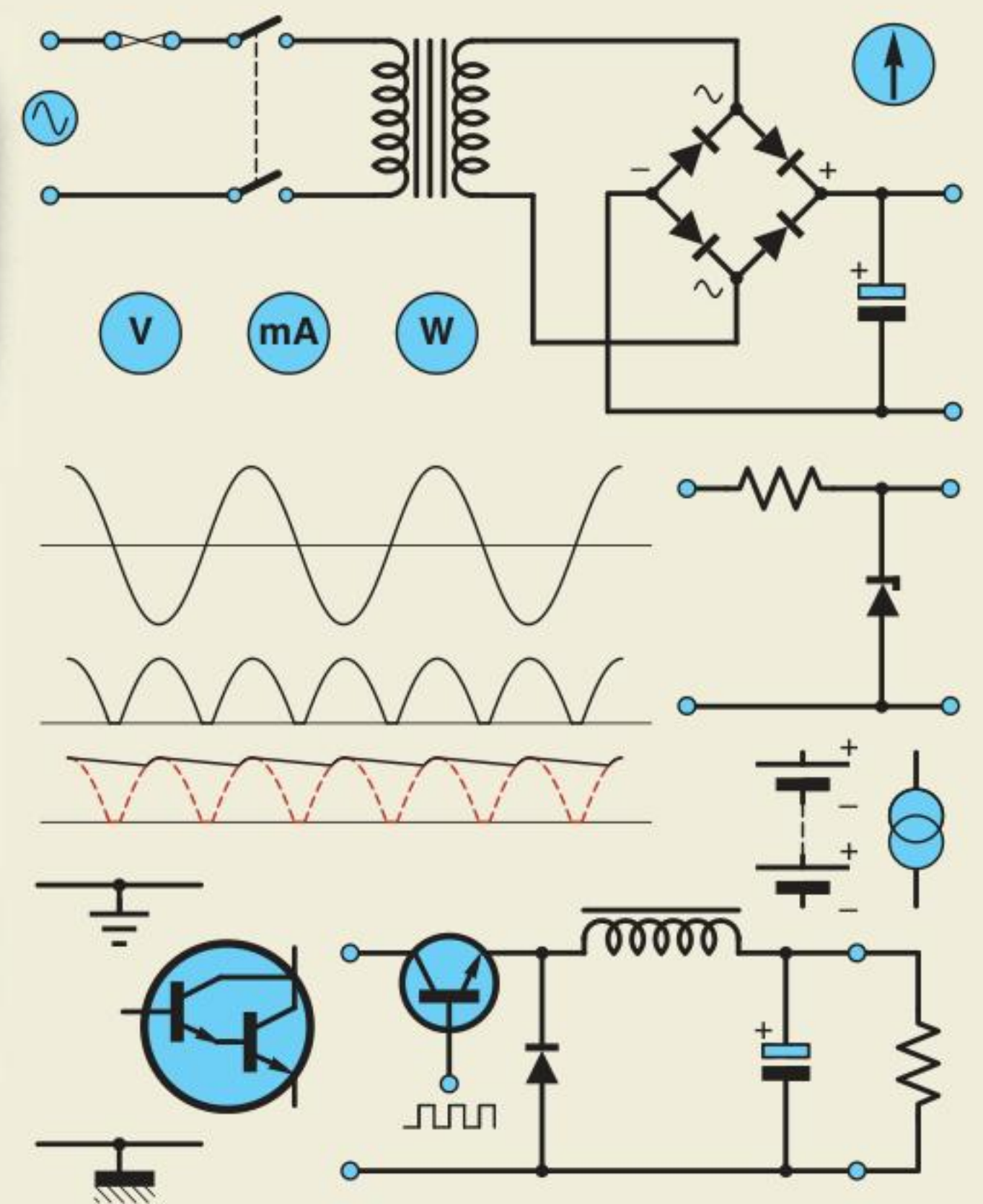
Fig.45. 1/4-inch jack plug with 820k Ω /91k Ω resistors for use as a scope lead – red wire to the 820k Ω .

Teach-In 2019

Powering Electronics

Part 4: Switched-mode power supplies

by Mike Tooley



Your project is finished and ready to go, but the job isn't done until you've found an appropriate source of power. This could be as simple as choosing a suitably rated mains adapter or as complex as designing a switched-mode power supply with multiple outputs and battery backup. Our latest series – *Teach-In 2019* – is

here to help, and will provide you with insight into all aspects of powering your electronic projects and designs.

In this fourth part we introduce switched-mode power supplies. These operate at efficiency levels that are well beyond those that can be achieved using the linear techniques that we met earlier

in the series and they also offer several other significant advantages including reduced weight and size. Our *Teach-In 2019 Practical Project* takes the form of a simple voltage booster that can be used in conjunction with a fixed three-terminal voltage regulator (see last month) to act as a handy 'battery extender'.

Switched-mode principles

Power supplies can be divided into two main types based on whether they use conventional linear circuitry or use switching techniques. The regulated DC power supplies that we've already met are the former type, where the regulating device operates through a continuous range of current and voltage according to the input and load conditions prevailing at the time. Switching power supplies, on the other hand, use digital techniques where a semiconductor device is switched rapidly on and off in order to control and regulate the mean voltage delivered to a load. This type of regulated supply is

commonly referred to as a 'switched-mode power supply' or SMPS for short. (You will often see the alternative but similar name 'switch-mode power supply' – it means the same thing.)

Compared with their conventional linear counterparts, the advantages of an SMPS are:

- Ability to cope with a very wide input voltage range
- Very high efficiency (typically 80%, or more)
- Small size, lightweight and compact
- Reduced heat dissipation (resulting from the increased efficiency).

The disadvantages of an SMPS are:

- Higher component count
- Relatively complex circuitry

- Appreciable noise generated (resulting from the high-frequency switching action).

SMPS terminology

The main types of SMPS are usually described as, 'buck' (step-down), 'boost' (step-up), or 'buck-boost' (step-up/step-down). Buck circuits produce output voltages that are less than the input voltage (but at increased current) while boost types produce output voltages that are greater than the input voltage (but at reduced current). Buck-boost types can be configured so that they will either step-up or step-down their input voltage.

An SMPS will usually convert (ie, step-up or step-down) the input voltage and also regulate the output voltage. These two

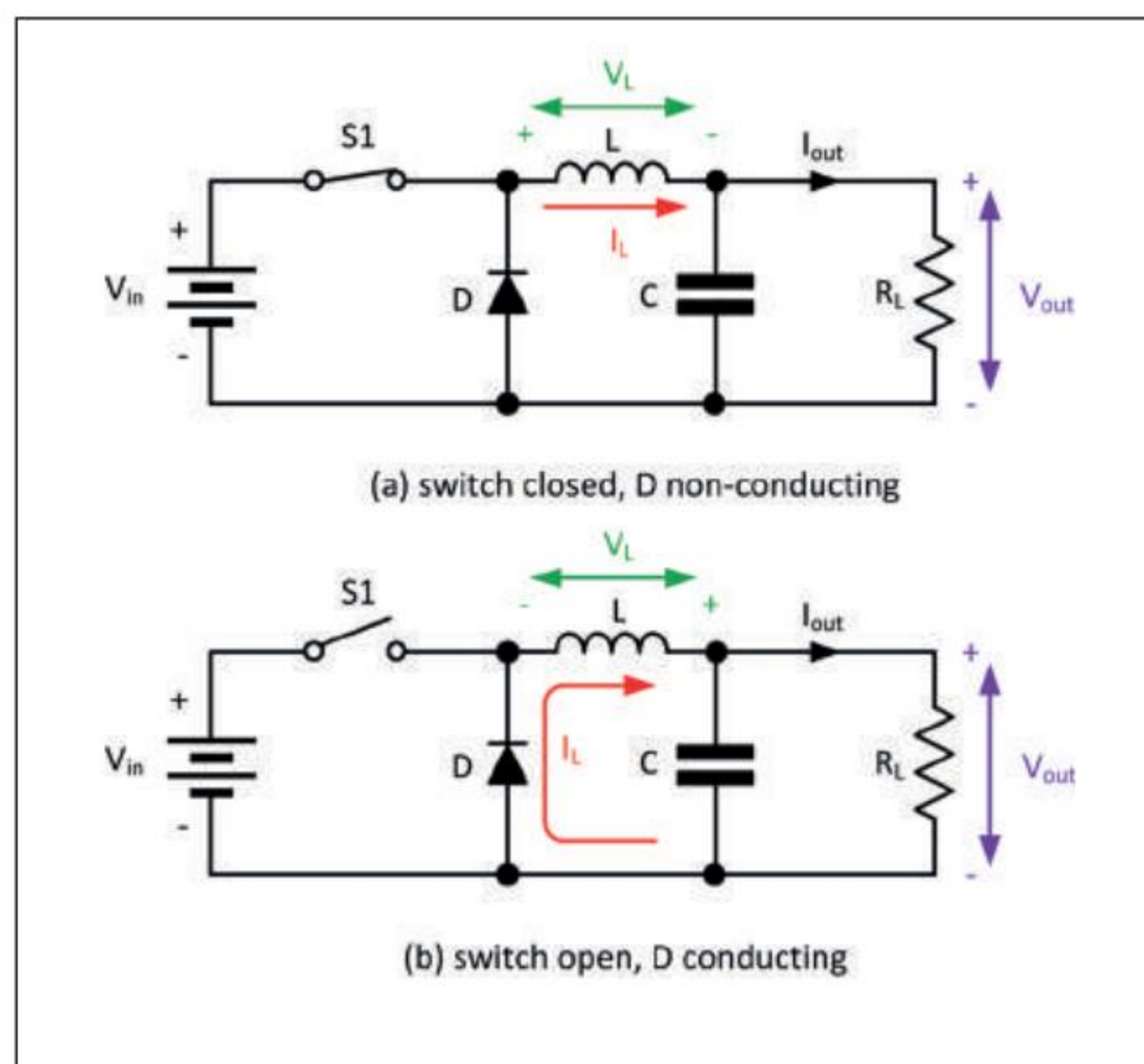


Fig.4.1. SMPS principle

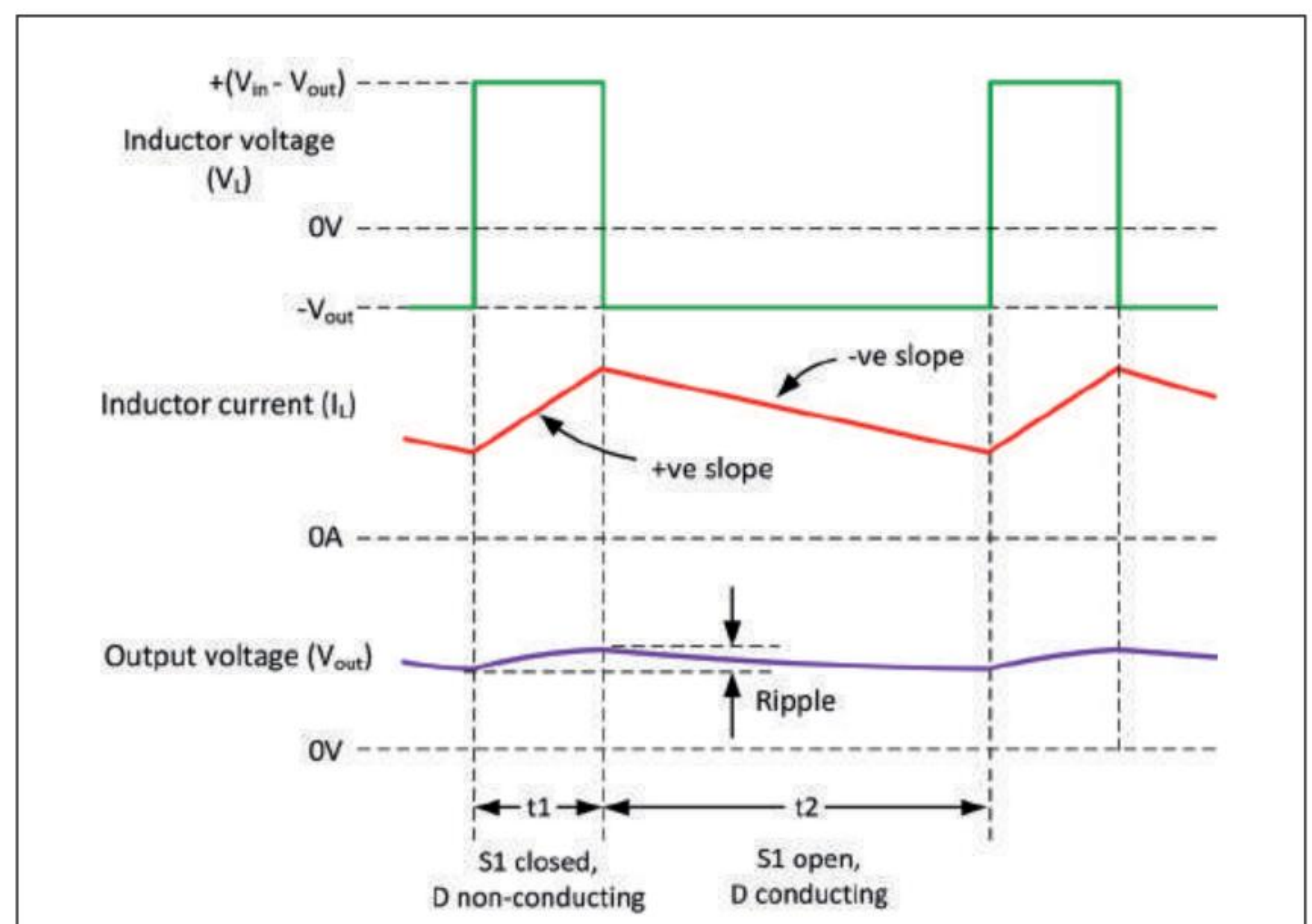


Fig.4.2. Waveforms of the current and voltages in Fig.4.1

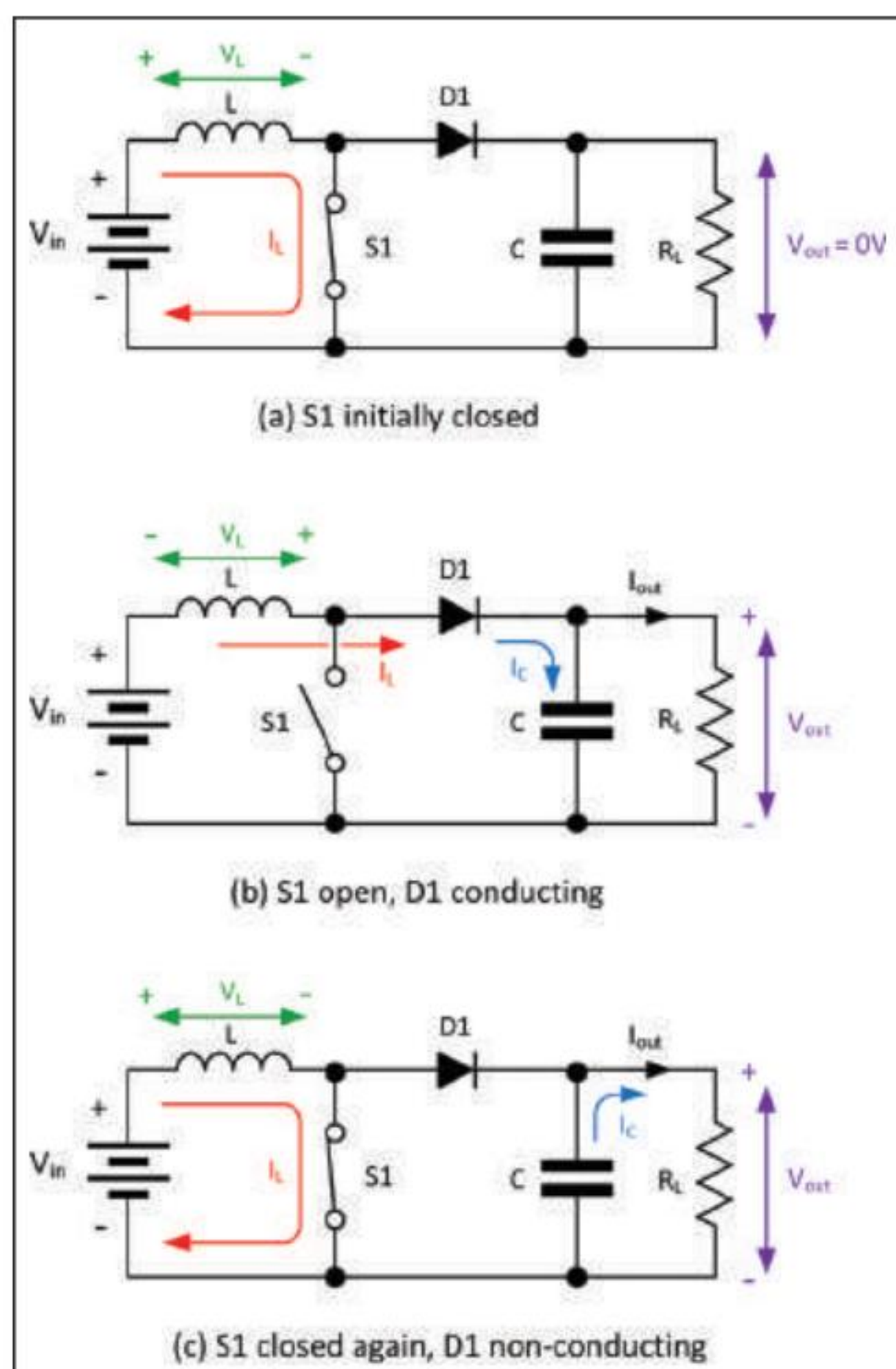


Fig.4.3. Principle of a switched-mode boost (step-up) converter.

functions (conversion and regulation) can be separate but, in practice, they are often combined within a design which, with the addition of a simple input rectifier and reservoir capacitor provides a reasonably constant DC output from an input AC mains supply.

In this series, the term 'switched-mode converter' will be used to describe a circuit which takes a DC input and provides a single or multiple DC output(s) of the same or opposite polarity and of lower or higher voltage. The term 'switched-mode regulator', on the other hand, will be used to describe a circuit that not only converts a DC voltage but also stabilises the output using a combination of switching and analogue techniques.

Buck (step-down) regulators

The principle of a buck (or step-down) switched-mode converter is shown in Fig.4.1. With S1 closed, the switching diode (D) will be reverse biased and will thus be in a non-conducting state. Current will flow through the inductor (L) charging the capacitor (C) as well as delivering current to the load (R_L).

Current flowing in the inductor (I_L) will produce a magnetic flux in its core. When S1 is subsequently opened, the magnetic flux within the inductor rapidly collapses and a voltage is generated across the terminals of the inductor. The polarity of the induced voltage is such that it opposes the original potential and will cause current to continue to flow in the load (ie, clockwise around the circuit). In this condition, D will become forward biased, completing the circuit in order to provide a return path for the current.

Waveforms for the circuit of Fig.4.1 are shown in Fig.4.2. The inductor voltage (V_L) is alternately positive and negative. When S1 is closed, the voltage dropped across the inductor (from left to right in the diagram) will be equal to $+(V_{in} - V_{out})$

and during this period the I_L will increase at a rate determined by the ratio of V_L to inductance, L .

During the time that S1 is open, the voltage across the inductor will be equal to $-V_{out}$ (less the small forward-voltage drop of D) and the I_L will fall. The average current through the inductor (I_L) is equal to the current (I_{out}) supplied to the load. Note that a small amount of ripple voltage appears superimposed on the steady output voltage (V_{out}). This ripple voltage can be reduced by using a relatively large value for the capacitor (C).

To control the voltage (V_{out}) delivered to the load it is simply necessary to adjust the ratio of 'on' to 'off' time of the switch. A larger ratio of 'on' to 'off' time (ie, a larger duty cycle or mark-to-space ratio) produces a greater output voltage, and vice versa.

In a practical switched-mode power supply, S1 is replaced by a semiconductor switching device (eg, a bipolar transistor or a MOSFET device). The switching device must have a low 'on' resistance and a high 'off' resistance and must be capable of switching from the 'on' state to the 'off' state in a very short time.

Regardless of whether it is a bipolar transistor or a MOSFET, a train of rectangular pulses applied to its base or gate terminal controls the switching device. Varying the width of the pulses in this train can control the output voltage. In a practical SMPS, a closed-loop feedback path is employed; the output voltage is sensed and fed back to the control input of a pulse generator. The result is pulse-width modulation (PWM) of the pulsetrain to the switching device. This pulse-width modulation can be achieved using a handful of discrete components or, more usually, is based on a dedicated switched-mode controller chip (see later).

Boost (step-up) converters

The principle of the boost (or step-up) switched-mode converter is a little more complex. Consider the circuit shown in Fig.4.3. Initially, the switch (S1) is closed and this produces a current in the inductor, L . Once again, the current flowing in the inductor (I_L) is instrumental in producing a magnetic flux in its core.

When S1 is subsequently opened, the magnetic flux within the inductor rapidly collapses and a voltage is generated across the terminals of the inductor. The polarity of the induced voltage is such that it is in the same direction as the input voltage and thus the voltage that appears at the anode of the switching diode is significantly greater than V_{in} . In this condition, the switching diode (D) will become forward biased, completing the circuit to provide

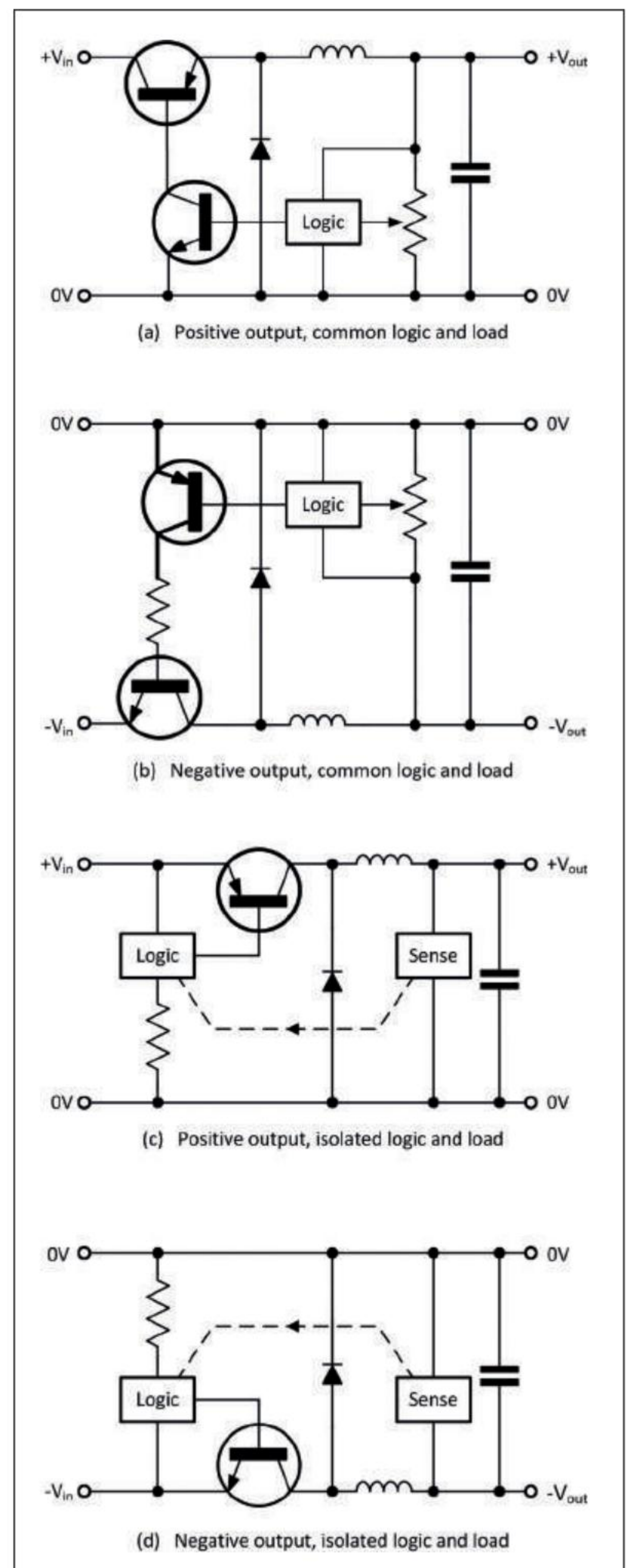


Fig.4.4. Step-down SMPS configurations

current that will charge the capacitor (C) and supply the load (R_L).

With S1 returned to the closed position, D will revert to its reverse-biased state and will be non-conducting. The charge stored in the capacitor should be sufficient to sustain current demanded by R_L .

Regulator configurations

Since most SMPS designs operate from a conventional AC mains supply and produce a low-voltage DC output, step-down regulators are much more common than step-up types. There are four basic configurations for a step-down switched-mode regulator, as shown in Fig.4.4.

In Fig.4.4(a) and 4.4(b), the logic circuitry (ie, the PWM controller) is connected to one side of the load, whereas in Fig.4.4(c) and 4.4(d) the logic circuitry is at a higher potential and therefore must be isolated from the load.

The situation is even more complex when the switching device(s) are operated directly from a high-voltage DC supply derived from a mains-connected bridge rectifier circuit. In this configuration it is essential to provide a very high degree of electrical isolation between the mains input, rectifier and switching circuitry, and the low-voltage side of the SMPS. To achieve the high degree of isolation required one or more optical isolators are normally used. We will revisit the need for isolation and the role of optical isolators next month.

SMPS applications

Regardless of the regulator configuration, an SMPS can take various forms according to how the switching device derives its DC input and whether electrical isolation between the input and output is needed. Just a few variants are shown in Fig.4.5.

DC input/DC output in either a buck or boost configuration

Fig.4.5(a) shows a typical application of a DC input / DC output SMPS. It provides a constant DC voltage from a nominal 13.5V vehicle supply. A step-up SMPS module can, for example, produce a constant 24V from a 13.5V vehicle battery, while a step-down SMPS module could produce 4.5V, 6V or 9V from the same nominal supply voltage.

'Battery extenders'

One common application of the DC input/DC output SMPS is in the so-called 'battery extender', as shown in Fig.4.5(b). This device uses a step-up regulator circuit and provides a near-constant DC output from a widely varying input voltage. As an example, one such device will operate with a DC input (derived from a conventional dry battery) of nominally 9V (but as little as 3V when the battery becomes exhausted) to produce a DC output of between 8.5V and 9V at load currents of up to 250mA.

AC input plus 50Hz transformer/DC output

Fig.4.5(c) shows an SMPS hybrid between a conventional transformer/rectifier/regulator arrangement and a true '50Hz transformerless' SMPS configuration. The advantage of this arrangement is that the 50Hz transformer provides isolation from the supply and the relatively low DC voltage permits the use of low-voltage switching devices. The obvious disadvantage of this technique is simply that the supply still requires a bulky and expensive transformer.

AC input plus high-voltage rectifier/DC output

The most common type of SMPS is illustrated in Fig.4.5(d). Here, the AC mains input is directly rectified (ie, there is no 50Hz mains transformer) using a bridge rectifier arrangement together with suitably rated reservoir capacitors to produce a high-voltage DC supply which is then applied directly to the switching devices. Instead of an inductor, the high-

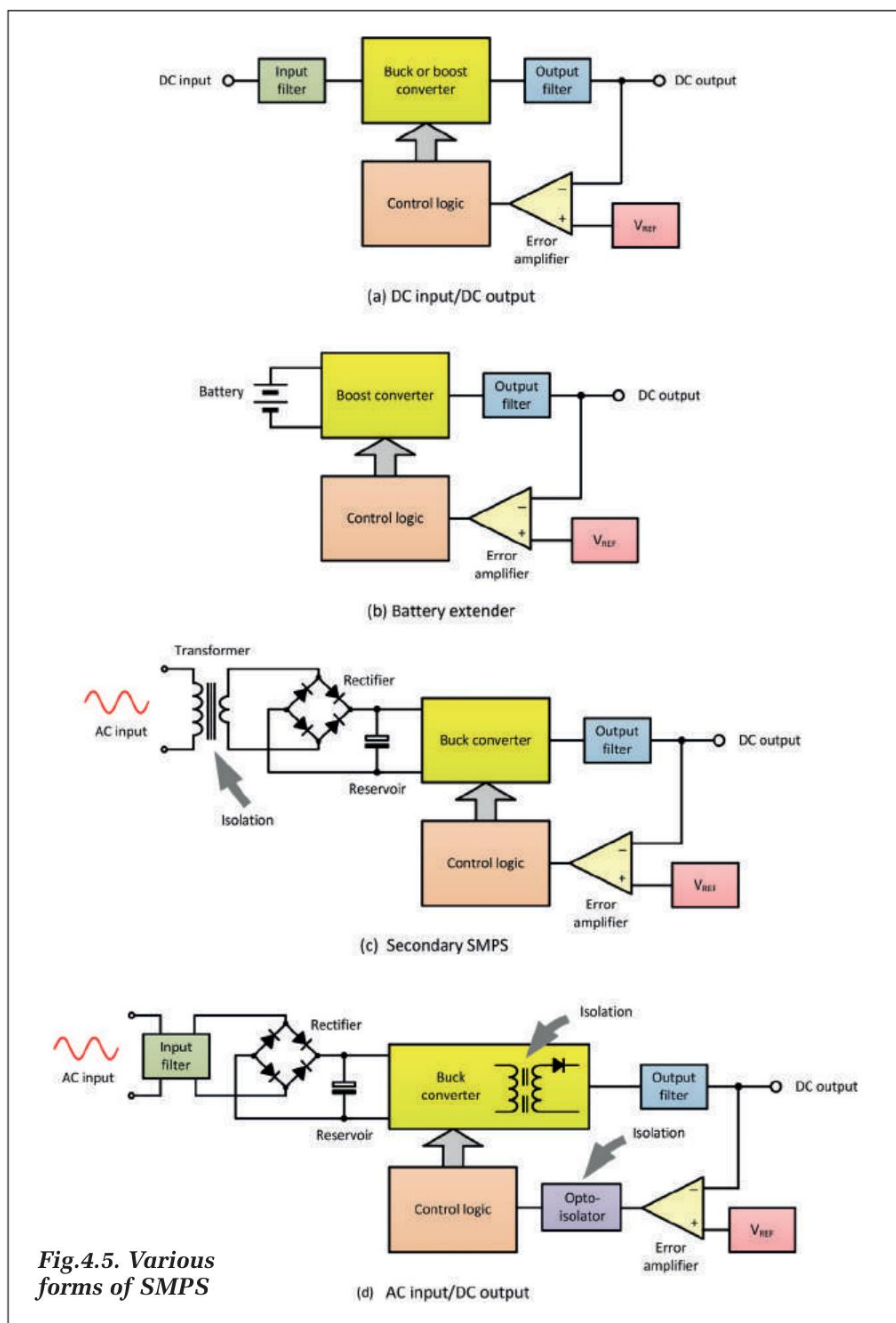


Fig.4.5. Various forms of SMPS

frequency energy is coupled using a high-frequency ferrite-cored transformer, into one or more secondary circuits, each with its own rectifier and smoothing arrangement. The DC output produced is then sensed and fed back via an opto-isolator, to the PWM control circuitry that generates a pulse train to control the high-voltage switching device(s). The operation of this design will be clearer when we describe typical circuitry next month.

Examples of SMPS supplies

Fig.4.6 shows a simple low-voltage (or 'secondary') SMPS. The low-voltage input can be either AC or DC (note that the module is fitted with a bridge rectifier (D1 to D4) and smoothing capacitor, C1). In most applications the 20V AC input will be derived from a suitably rated 50/60Hz step-

down transformer. The output voltage of the supply is nominally 12V at load currents of up to 2.7A. The circuit uses just two transistors (TR1 and TR2) and one integrated circuit (IC1). The circuit of the secondary SMPS is shown in Fig.4.7, and its specification is:

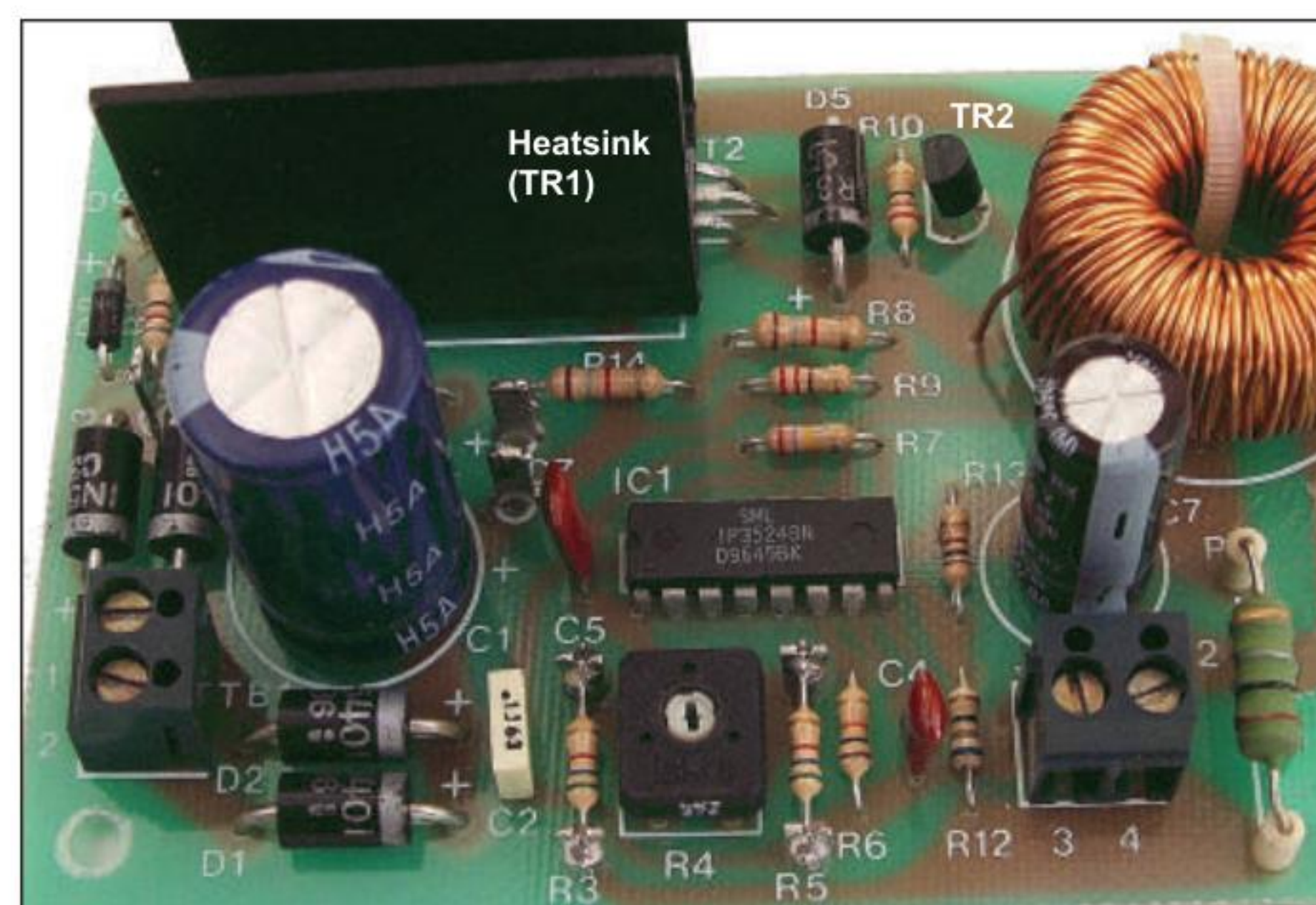
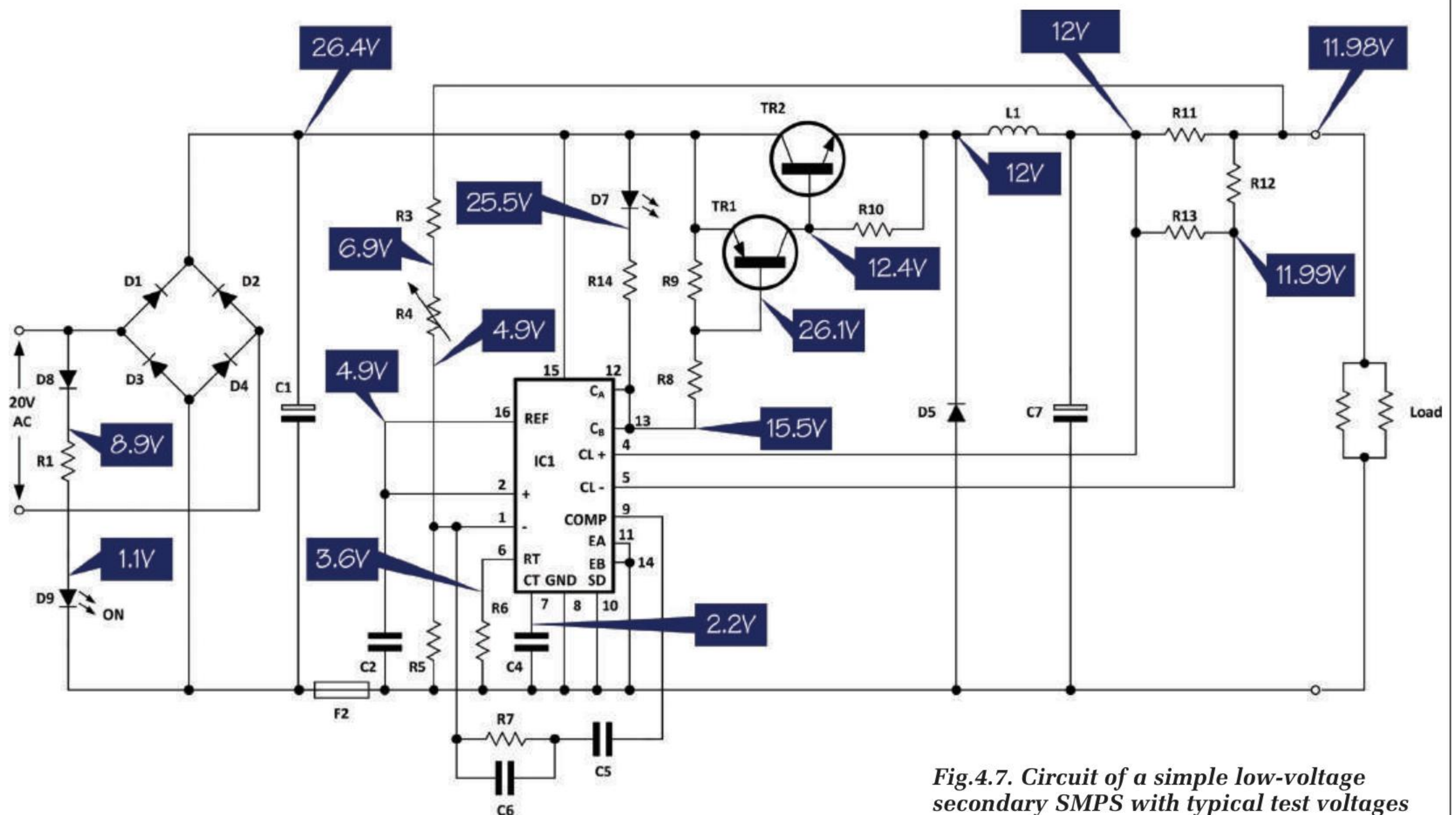


Fig.4.6. A simple low-voltage secondary SMPS



Output voltage range	+12V (can be configured for other voltages)
Output current	2.7A (maximum)
Input voltage range	+10V to +35V DC or 20V AC
Line regulation	20mV (maximum)
Load regulation	60mV (maximum)
Short-circuit output current	3A (nominal)
Switching frequency	58kHz (nominal)

It is fairly easy to identify the components used in Fig.4.6 and Fig.4.7 which are responsible for the main SMPS controller functions; they are:

- C4 sets IC1's basic switching frequency
- R3 and R4 together with R5 form a potential divider that determines the output voltage
- R8 limits the base current to driver transistor TR1
- R11 in conjunction with R12 and R13 set the output current limit
- TR2 is the switching device (mounted on a heatsink)
- LED D7 indicates that current is being drawn from the circuit
- LED D9 indicates that the supply input is present.

The primary SMPS supply shown in Fig.4.8 is more complex. This unit operates from AC mains input and provides multiple DC outputs of +5V at 12A, +12V at 3A, +8V at 2A, and -8V at 1A. The power supply is rated for a maximum total load of 100W and it exhibits a load regulation of 0.5% for the +5V output and 5% for the 12V output. The noise present on the +5V has a maximum amplitude of 50mV. It is worth noting that the supply requires a minimum load of 10% to ensure proper regulation of the remaining outputs. This is important, since *off-load* SMPS measurements can often be somewhat confusing!

The SMPS controller (IC1) has an internal 5V regulator that serves both as

a voltage reference and delivers power to the chip's internal control circuitry. The regulated 5V supply is also made available for use by external circuitry.

The budget primary SMPS shown in Fig.4.9 provides a single regulated output of +5V at 4A with a load regulation of better than 1%. The supply is intended for either 110V or 220V AC mains, but any input voltage can be used within the range 85V to 264V AC.

We've shown both sides of the printed circuit in 4.9 so that you can see the physical separation of the high-voltage AC/DC 'primary side' components (on the left of Fig.4.9) from the low-voltage DC 'secondary side' components (on the right of Fig.4.9).

Comparison of linear and SMPS technology

Before we go much further, it is very important to understand the differences between linear and SMPS technology. In a conventional linear power supply operated from a low-frequency 50/60Hz

Important safety note

The voltages found in an SMPS can be lethal. When working on a mains input SMPS it is essential to avoid contact with any metal parts or components that may be at a high AC or high DC potential. This includes all mains wiring, the mains input noise filter, the AC rectifier, high-voltage smoothing capacitors, switching transistors and diodes. A sensible precaution when making measurements on an SMPS is that of only working with one hand (you should keep the other one safely behind your back or in a pocket). This simple practice will ensure that you never place yourself in a position where electric current can pass from one hand to the other via your heart. In such circumstances an electric shock could be fatal.

Most kinds of SMPS use two separate common/ground connections. One of these is not isolated from the AC mains supply (we shall be referring to this as the 'non-isolated common connection'). The other common/ground connection is on the low-voltage side of the SMPS and is usually connected to the chassis (or frame) ground connection (we shall be referring to this as the 'common ground connection'). The two common /ground connections should never be linked together. You should also avoid making an earth/ground connection from your mains-operated test equipment to the non-isolated common connection on an SMPS. Failure to observe this precaution can result in damage to your test equipment as well as the SMPS.

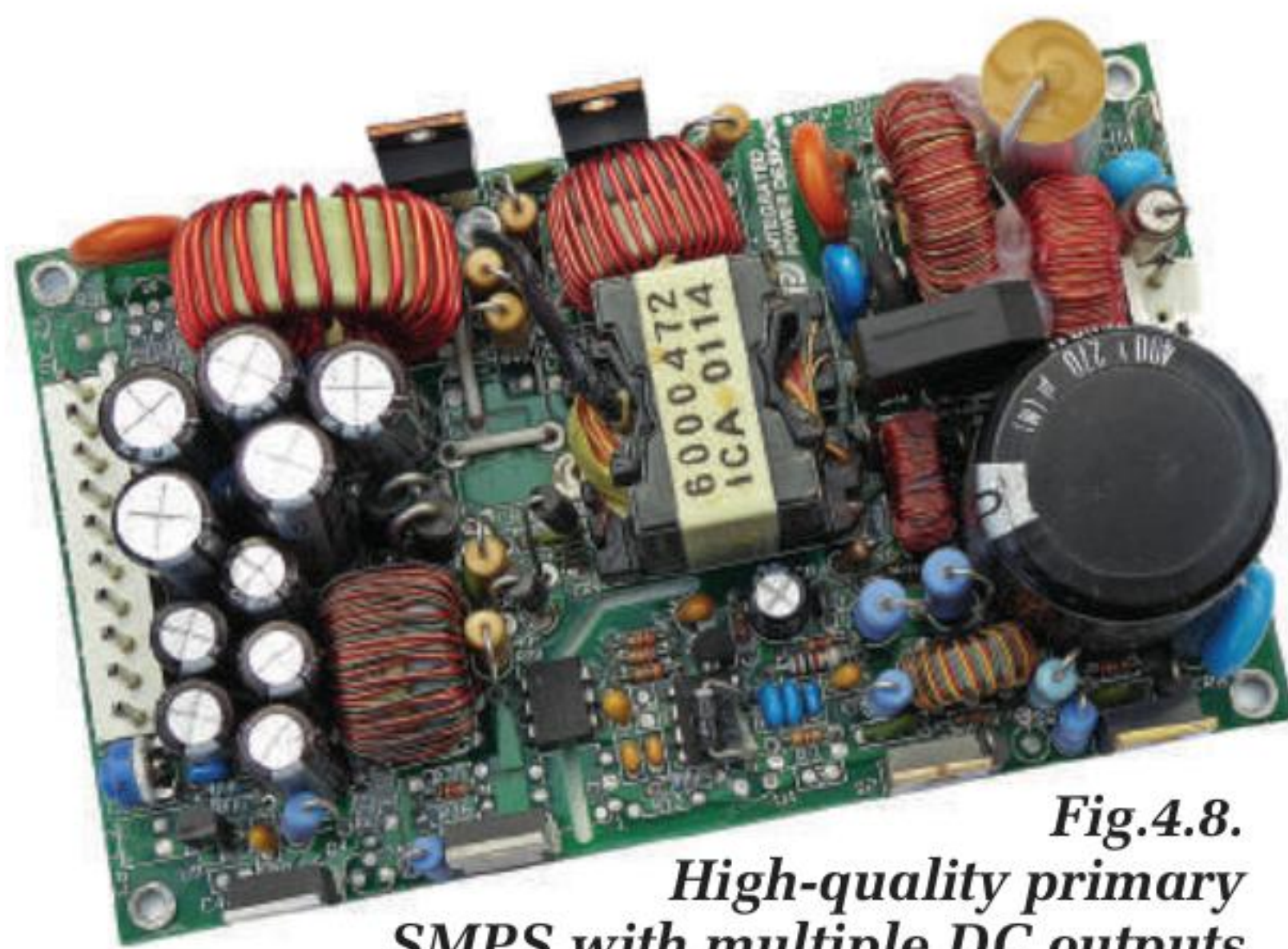


Fig.4.8.
High-quality primary SMPS with multiple DC outputs

AC mains supply, a laminated steel-cored transformer operates at mains supply frequency to provide both isolation and the ability to step voltages up or down.

The secondary voltage from the transformer is then fed to a rectifier and smoothing circuit, which then supplies the DC input required by a conventional linear voltage regulator. By contrast, in an SMPS the functions of isolation, voltage conversion and regulation are all essentially combined within the same circuit. However, whereas the transformer used in a conventional power supply is bulky and expensive, the equivalent component used in a SMPS is much more compact and less expensive. The reason for this is the high switching frequency used (typically

between 50kHz and 100kHz) whereas the substantial increase in efficiency results mainly from the fact that the active devices used to perform the switching of current in the transformer primary winding(s) operate under class-C rather than linear (class-A/B) conditions.

A further important feature is that the high-frequency transformers and inductors used in an SMPS have ferrite dust cores as opposed to the laminated steel cores of their mains frequency counterparts. SMPS transformers and inductors also have fewer turns in their windings than the mains frequency transformers. This all serves to make them smaller and lighter than their low-frequency counterparts.

Conventional series-regulated linear power supplies maintain a constant voltage by varying their 'resistance' to cope with input or load demand changes. The linear regulator can, therefore, be very inefficient. The switched-mode power supply, however, uses a power-switching device (invariably a high-voltage power transistor) with varying duty cycle to maintain the output voltage.

After rectification, the superimposed noise caused by fast switching transients

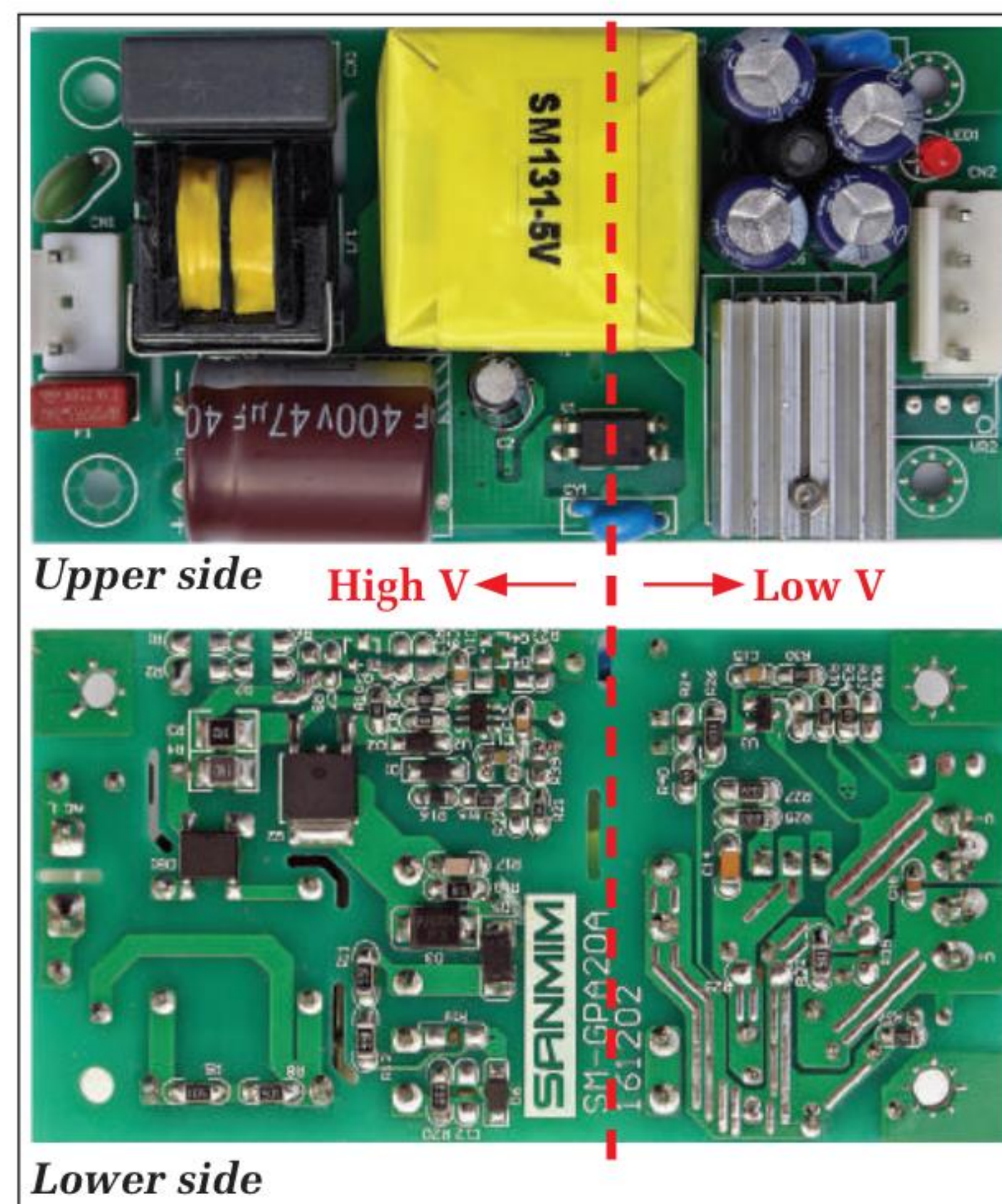


Fig.4.9. A budget primary SMPS with a single +5V 4A output. The high-voltage AC/DC primary side components are on the left; the low-voltage DC secondary side components are on the right.

will need to be removed by one or more appropriately designed low-pass filters. We will be exploring this in more detail later in the series.

Practical Project: Switched-mode boost converter

This month's *Practical Project* takes the form of a switched-mode boost converter designed for use in conjunction with a fixed-voltage regulator (see last month). This simple 'battery extender' produces a well-regulated 12V output from a nominal 7V DC input (derived from two lithium-ion cells). The voltage booster operates with a typical efficiency of up to 85% and with input voltages between 5V and 10V. The maximum load current of 0.8A is sufficient to meet the demands of a wide variety of low-power portable devices.

The circuit of our switched-mode boost converter is shown in Fig.4.10.

A conventional timer (IC1) provides a square wave output at about 70kHz to drive the gate of the switching transistor (TR2) via R3. The square wave pulse waveform appearing at the drain of TR2 is rectified by means of a fast-switching diode (D1). C4 acts as a reservoir capacitor while R4 and D2 provide an indication of the presence of a DC output voltage.

You will need...

- 1 Perforated copper stripboard (24 strips each with 37 holes)
- 2 2-way PCB screw terminal connector (ST1 and ST2)
- 1 1kΩ resistor (R1)
- 1 10kΩ resistor (R2)
- 1 100Ω resistor (R3)
- 2 22µF 35V capacitors (C1 and C4)
- 1 1nF capacitor (C2)
- 1 100nF capacitor (C3)
- 1 470µH ferrite-cored inductor (L1) (see text)

- 1 555 8-pin DIL timer
- 1 RFP30N06LE (TR1) (see text)
- 1 BYW29 (D1) (see text)
- 1 red LED
- 2 small TO220 heatsinks (see text)
- 4 stand-off pillars and mounting screws
- 1 8-pin DIL socket

Construction

The switched-mode boost converter's layout is shown in Fig.4.11. Note that there are 29 track breaks and seven links. The pin connections for the semiconductors are shown in Fig.4.12. The two TO220 heatsinks should be rated at 9.1°C/W, or better. Furthermore, to improve heat dissipation the two power semiconductor devices (TR1 and D1) are mounted directly on their respective heatsinks. These should not be allowed to make contact with the enclosure or any other component parts. As always, once assembly is complete it is well worth carrying out a careful inspection of the circuit board, particularly checking the off-board wiring and links to ST1 and ST2.

We have used very conservatively rated devices for TR1 and D1. Both of these devices are reasonably common but many similar semiconductor devices are available and can be used instead. For example, TR1 can be any suitably rated N-channel MOSFET switching transistor with a maximum voltage rating of greater than 50V and an 'on' resistance of less than 0.1Ω (note that the drain connection of this device is connected directly to the mounting tab and therefore it will be at the same potential as the heatsink when no insulating washers are fitted). D1 is an ultrafast rectifier designed specifically for

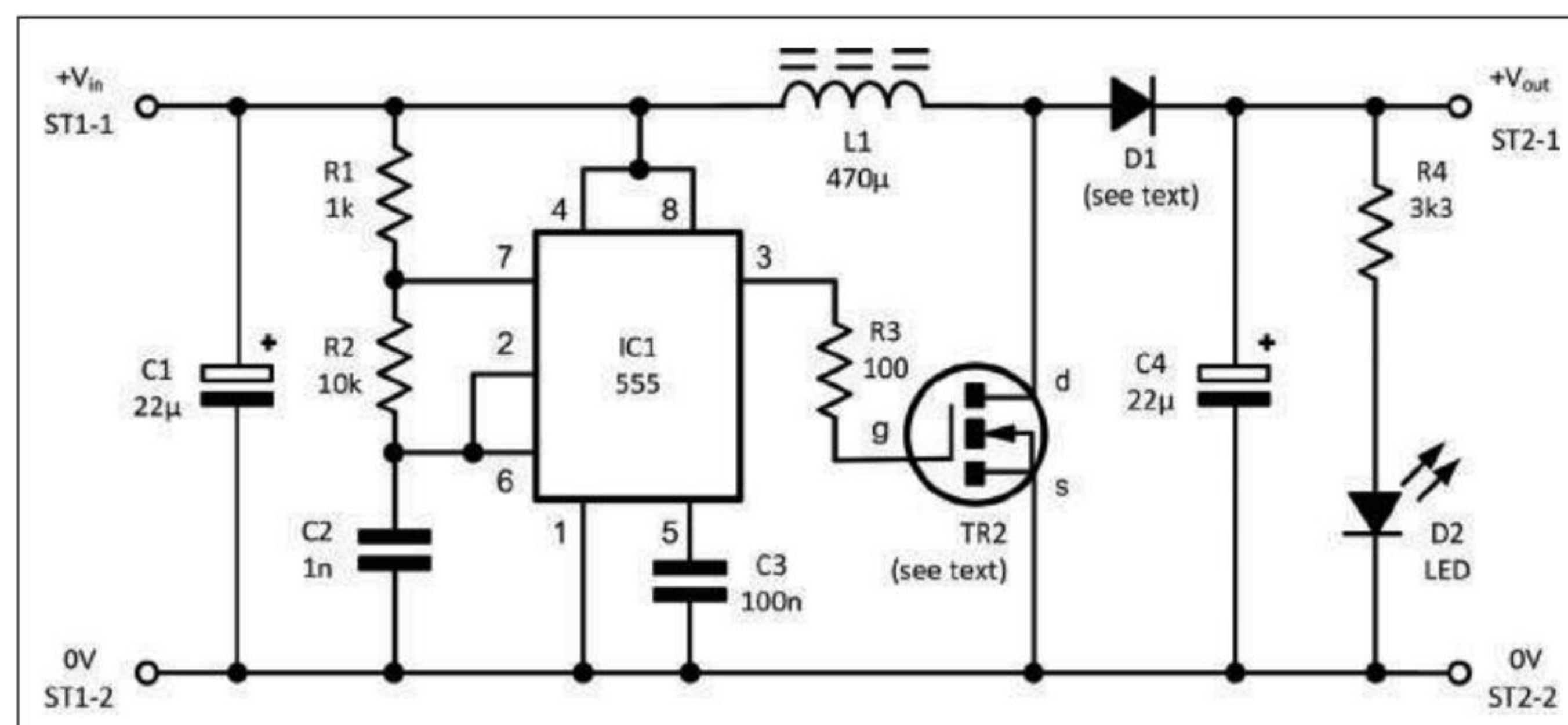


Fig.4.10. Circuit of the switched-mode boost converter

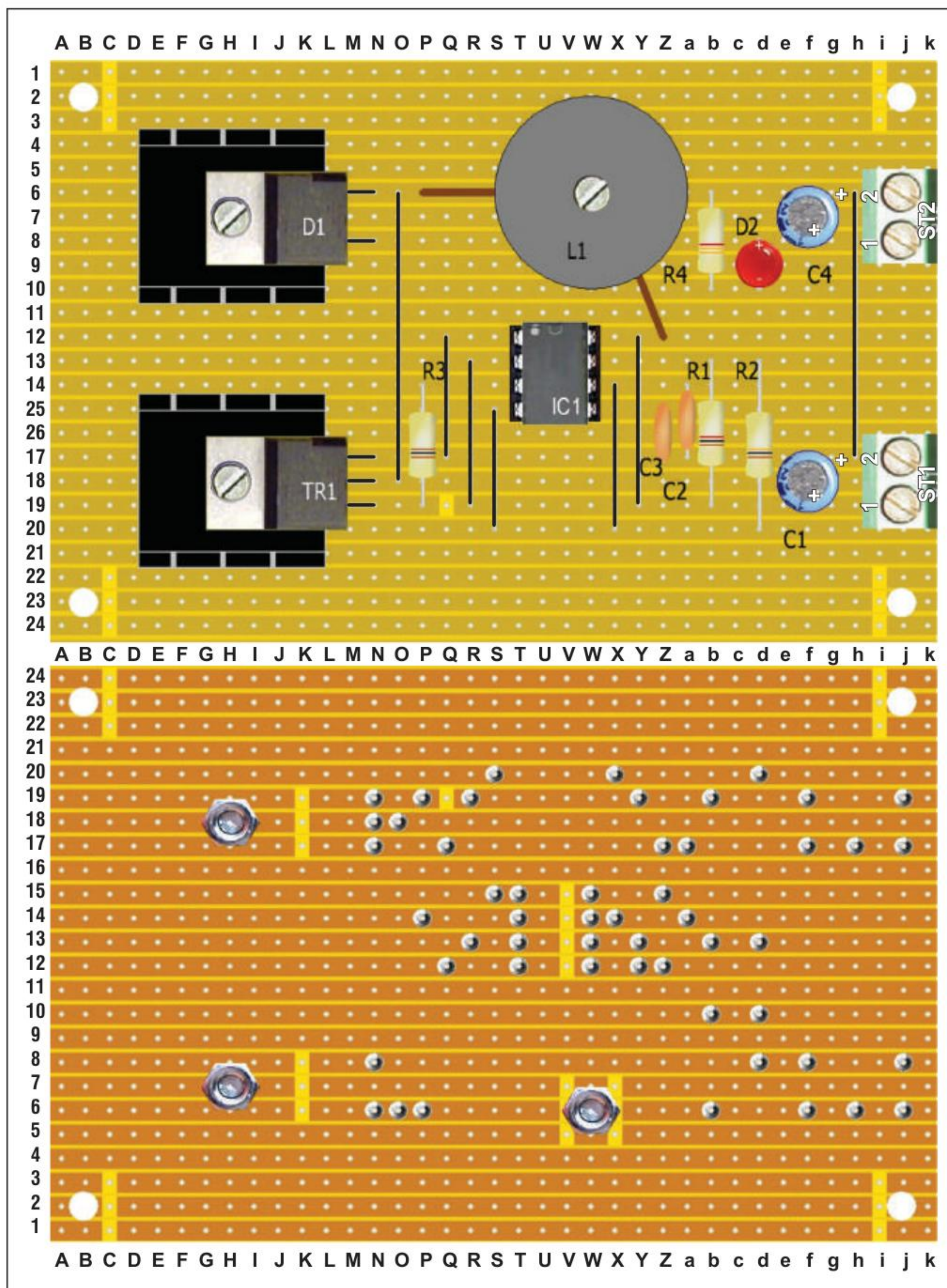


Fig.4.11. (Left) Stripboard layout of the switched-mode boost converter

use in a wide range of SMPS designs, but any similar device can be used provided that it is rated for a current of at least 5A and a voltage of greater than 50V. Finally, the ferrite-cored inductor used in the switched-mode boost converter must be rated at 2A and have a DC resistance of less than 0.3Ω . A suitable component is available from Murata Power Solutions (part number 1447423C) as sold by mouser.co.uk (580-1447423C). We will be discussing ferrite components in a later *Teach-In 2019* article.

Battery extender

Our switched-mode boost converter does not incorporate feedback voltage regulation and its output can vary from around 18V under no-load conditions to around 12.5V when supplying a load of 1A. This may be unimportant in some applications; however, where a constant output voltage is required, a simple three-terminal linear voltage regulator can be easily added in order to maintain a steady output voltage under load. With this in mind, the switched-mode boost converter can make the basis of a simple but effective battery extender, along the lines shown in Fig.4.14. This arrangement can maintain an output of 12V (at load currents of up to about 0.8A) when the switched-mode booster is supplied from two series-connected lithium-ion batteries (eg, two 18650 cells with a nominal 3.7V output per cell).

Next month

In next month's *Teach-In 2019* we will be exploring switched-mode controllers in greater detail and our *Practical Project* will take the form of a secondary SMPS that provides a regulated output.

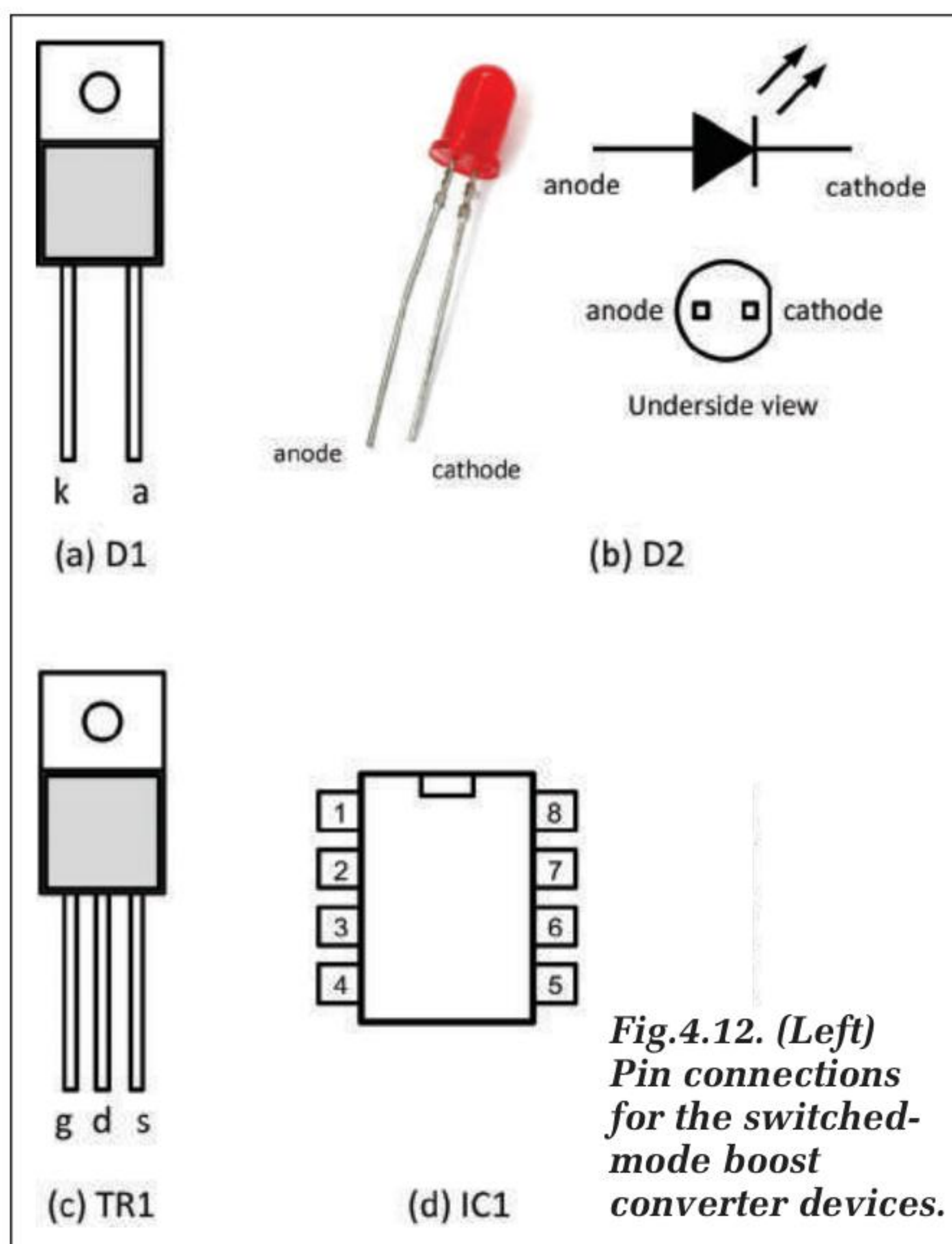


Fig.4.12. (Left) Pin connections for the switched-mode boost converter devices.

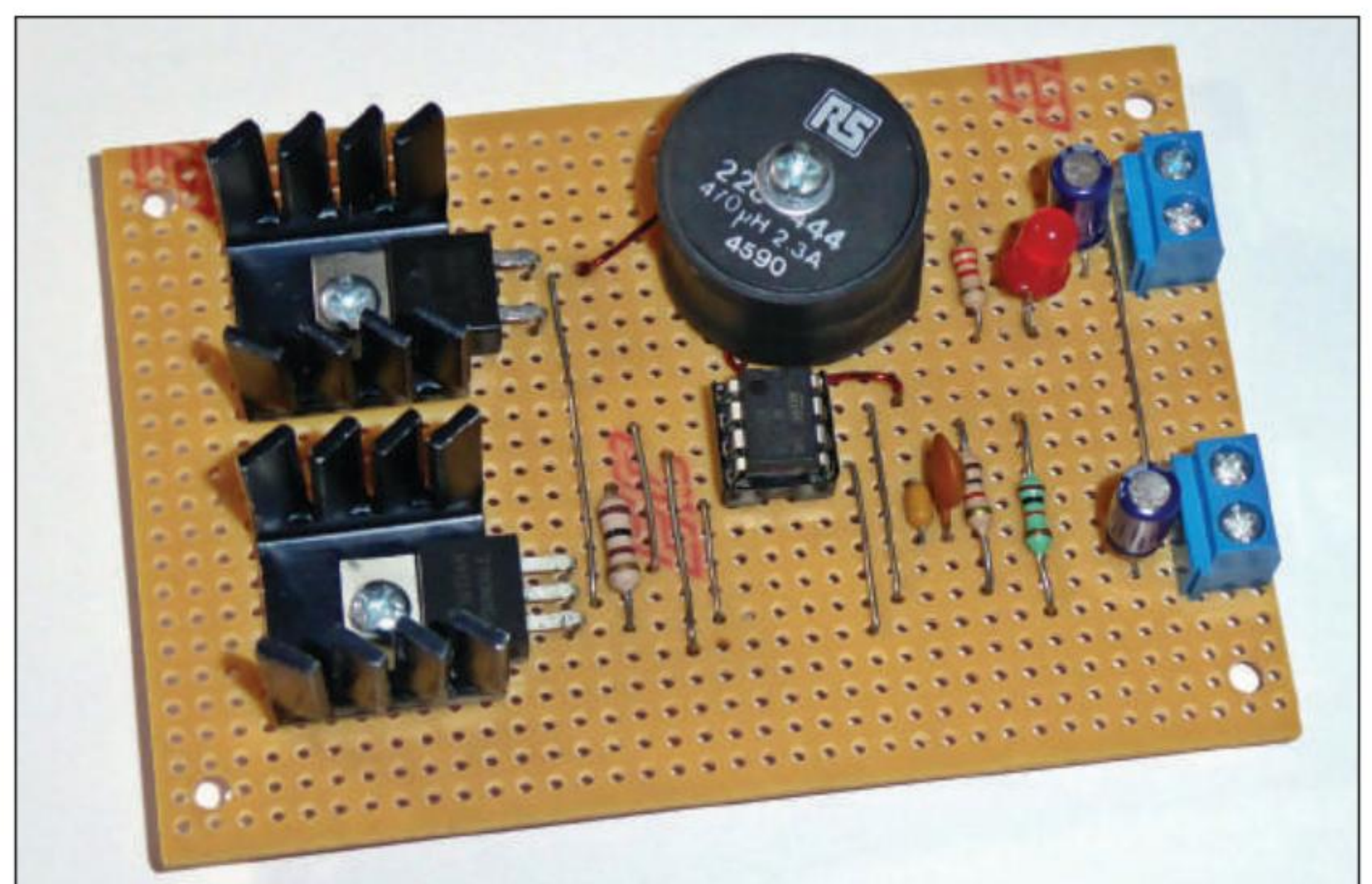


Fig.4.13. The finished switched-mode boost converter

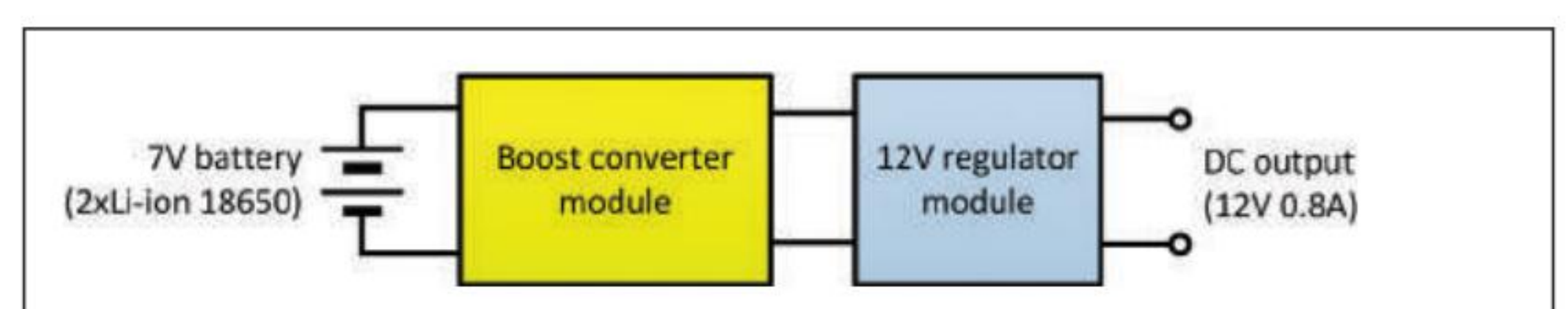


Fig.4.14. Using the switched-mode boost converter in a simple 12V 0.8A battery extender

Get it Right! – Selecting and fitting fuses

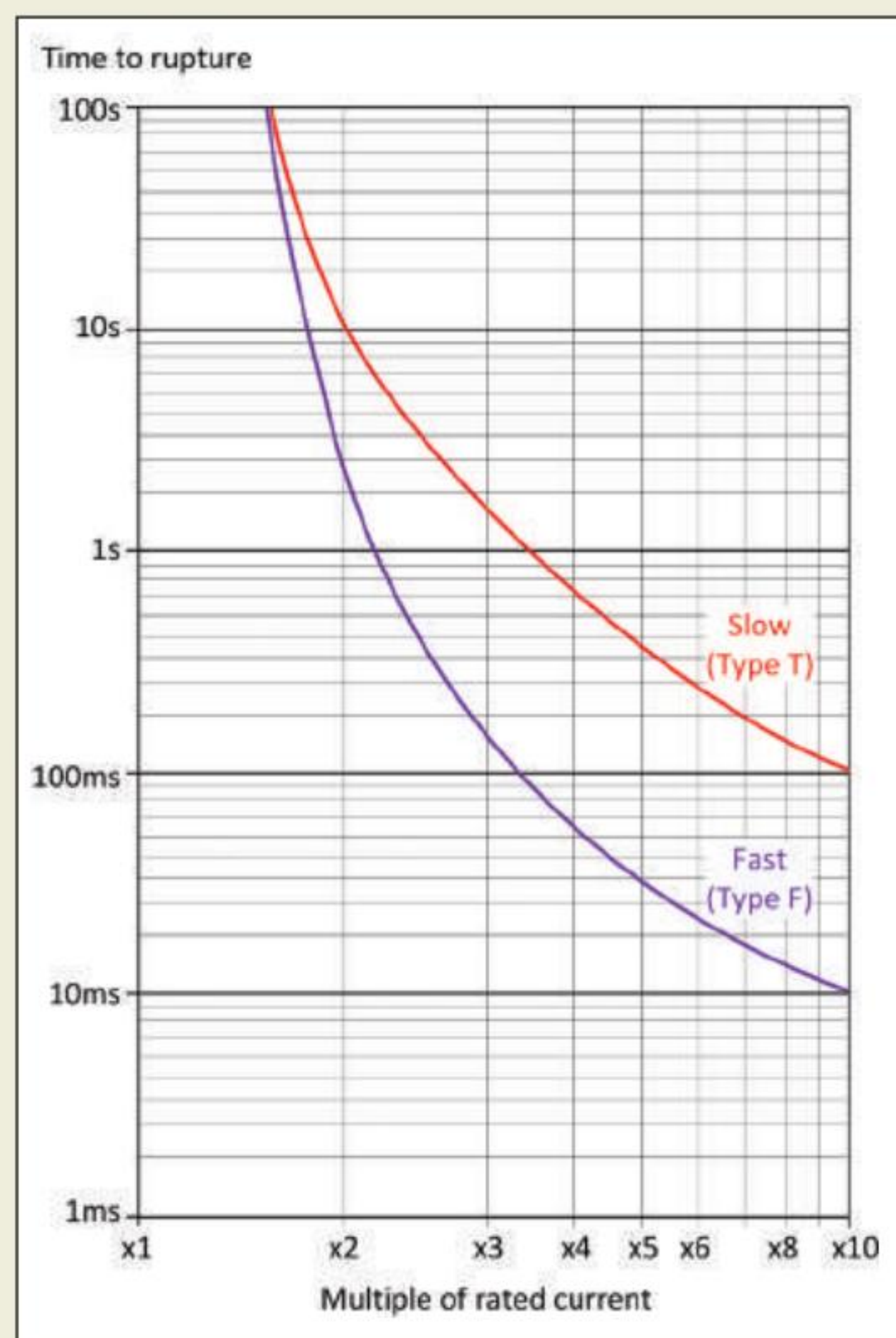


Fig.4.15. Typical operating characteristics of two common types of fuse. Type F is a ‘quick-blow’ fast acting type while Type T is a ‘slow-blow’ delayed action fuse. They are used in quite different applications!

Last month, our *Get it Right!* feature showed you how you can safely connect your equipment to an AC mains supply. This month, we explain the role of fuses and how they can be used to provide protection both for the AC supply as well as the load to which the supply is connected. If you followed the advice given last month you will already have some protection for the AC supply in the form of the fuse fitted to a plug connector that forms part of a standard IEC mains lead. This component is usually rated at 5A and **it should never be replaced by a 13A fuse**. In *Part 8* of this series we will be taking a more detailed look at this subject, but for now we will concentrate on additional protection that should be incorporated at the AC mains input in the form of an *equipment fuse*. This should be located within the equipment itself and its type and rating should be carefully chosen.

When selecting an equipment fuse it is necessary to consider several factors, including normal operating current, application voltage (and whether AC or DC), ambient temperature, overload current and the time before the fuse

must open. In addition, it might also be important to consider the maximum available fault current as well as the nature of the load current and whether it is susceptible to large values of inrush current or intermittent transient surges. Note that the rated current for a fuse is that which the fuse can withstand indefinitely. It is important to remember that fuses take a finite time to operate – they don’t operate instantaneously! Most fuses can be expected to open within two minutes at 200% of rated current but withstand 125% of rated current for a much longer period. The typical operating characteristics for two different types of fuse are shown in Fig.4.15.

When selecting and fitting an equipment fuse, the four essential precautions that will keep you and your equipment safe are:

1. Use only standard 20mm glass encapsulated fuses (see Fig.4.16). They should be fitted in an insulated fuse holder, ideally panel mounted in order to permit easy fitting and replacement. The fuse holder should be clearly marked with the required fuse rating.
2. Select the correct fuse rating in terms of working voltage and rated current. For mains-operated equipment the working voltage should be 250V and the current rating (I_R) should be selected using the relationship:

$$I_R = \frac{\text{Max expected load current}}{0.75}$$

The selected fuse rating should be the next higher available current. So, for example, if the maximum expected load is 0.3A the rated current will be 0.4A and a fuse marked 0.5A (500mA) would be suitable. Note that fuses are normally rated for operation at 25°C. When operating at high or low temperatures it may be necessary to select a different rating (we will explain this in greater detail in *Part 8*).

3. Select a fuse with the required characteristic in terms of its operating speed. Where the load current is constant and there is no appreciable inrush current at switch ‘on’, a ‘quick-blow’ or ‘fast’ (Type F) fuse should be selected. Conversely, where there is a large inrush current at switch on (for example, when large values

of reservoir capacitor are used) the fuse should be a ‘slow-blow’ or ‘slow’ (Type T) component. Note that there are several other categories of fuse (including the less common Type M component). In *Part 8* we will explain their operation in greater detail. The appearance of the different types is shown in Fig.4.17.

4. Fuses should be connected according to Fig.3.28 (see page 42 of February 2019 *EPE*). If only one equipment fuse is fitted it should be wired in the live mains connection (**never in the neutral connection**).

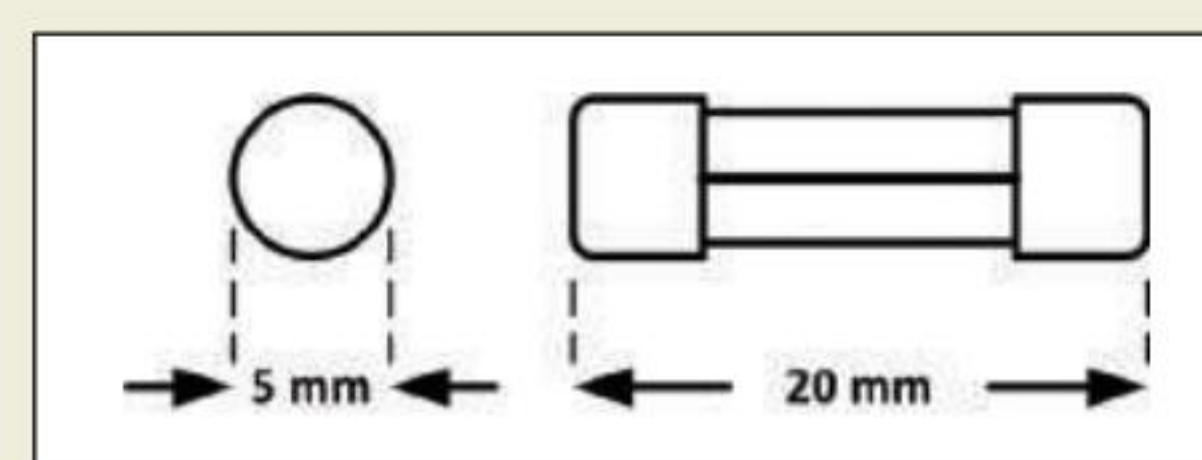


Fig.4.16. A standard fast-acting 20mm fuse (the fuse rating is usually marked on the end cap)

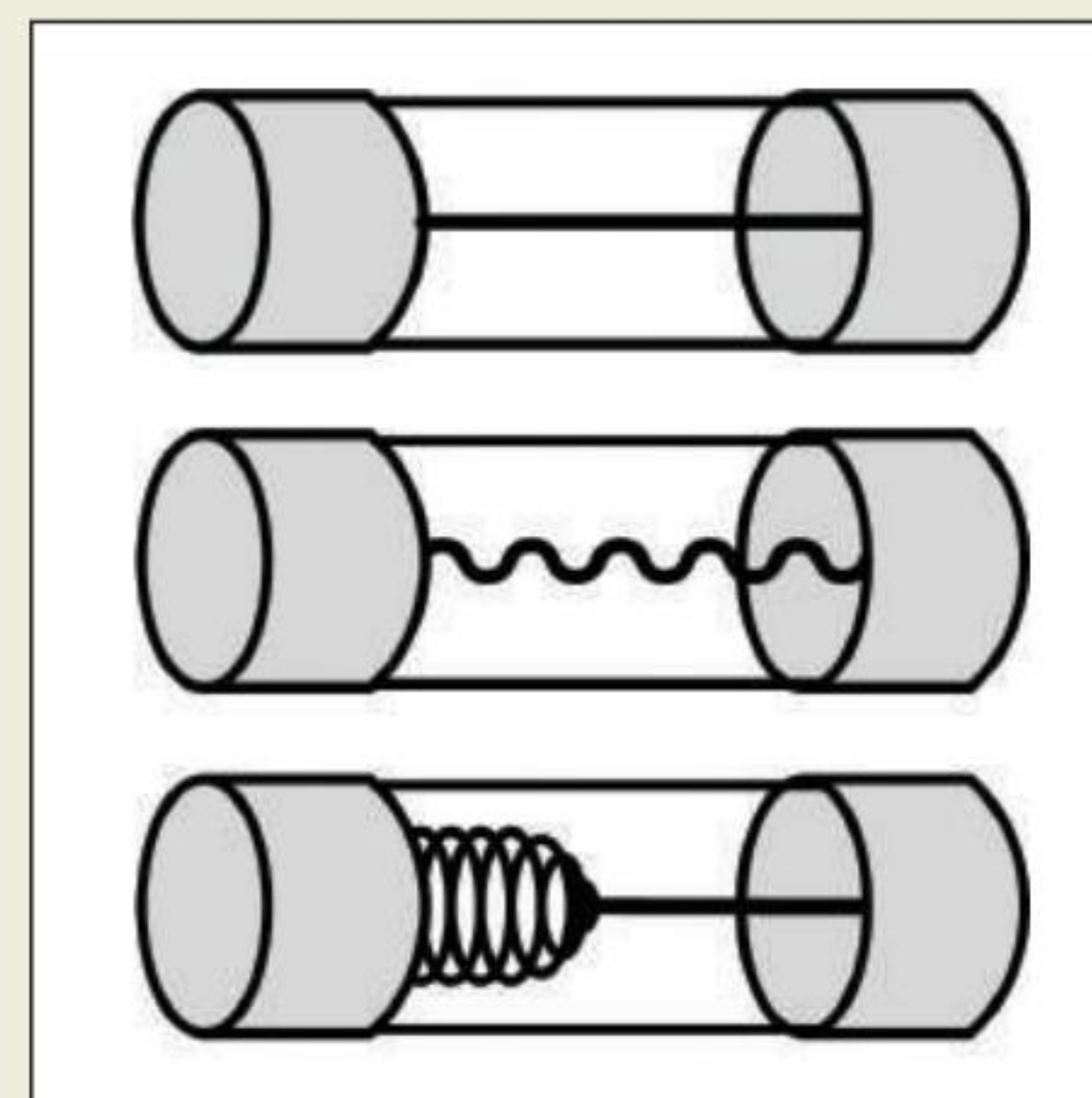


Fig.4.17. Appearance of three different types of 20mm fuse. Top to bottom: Type F and FF; Type M; Type T and TT).



Fig.4.18. A fused mains selector combines mains voltage selection with a standard 20mm fuseholder and IEC mains connector (a larger current rating will be required for 110/120V operation). Note the equipment’s external earth connection that permits local ‘grounding’ to other equipment

Max's Cool Beans

By Max the Magnificent



I've said it before and I'll say it again, 'Show me a flashing LED and I'll show you a man drooling.' To be honest, I can't imagine life without microcontrollers (MCUs) and LEDs. Apart from anything else, I love the fact that there are always so many different ways one can go about implementing things.

Suppose, for example, that we want to take an audio signal, split it into a set of frequency components (eg, base, middle, treble, and subdivisions thereof), and then use these components to drive a bunch of LEDs. One way to do this would be to use the amplitude of each frequency component to control the brightness of one or more LEDs. As you can see in the first part of this video (<https://bit.ly/1TgPf69>), this is the approach I used for the audio mode associated with my entry to a *Cunning Chronograph* competition from a few years ago.

By comparison, in his entry to this competition, my chum Steve Manley always drove his LEDs fully on. However, as you can see in this video (<https://bit.ly/2Qjb2hX>), Steve used the *number* of LEDs that were activated to reflect the amplitudes of the frequency components.

Another difference between our solutions was that I fed the audio signal into my *Cunning Chronograph* via a cable, while Steve opted to use a microphone. I was very impressed with Steve's microphone-based solution, which I tabled away in the back of my mind for use at some future time. Well, that time has come!

Audio-reactive artifacts

A few months ago, I was introduced on Kickstarter to an audio-reactive device called a Muzio (<https://bit.ly/2QIXG12>). This little rascal is really rather clever. It comprises a column formed from 26 acrylic discs, each of which is equipped with a number of tri-coloured LEDs. The



Fig.1. Max's portmanteau of delights



Fig.2. A few of my many retired (broken) vacuum tubes.

base contains an Arduino, a microphone, and a pushbutton to select between a variety of presentation modes. The Muzio also boasts an automatic gain control (AGC) feature, which means it will adapt to relatively low-level noises, like people talking, all the way to high-amplitude sounds like Greta Van Fleet belting it out in my office.

I'm a weak-willed man. I couldn't help myself. I ordered one. (Steve is a weaker-willed man; he ordered two.) When my Muzio arrived I immediately set it running. I love it, but it made me want to create my own audio-reactive artifact.

Bits and pieces

A few years ago, I gave a presentation at an Embedded Systems Conference. The topic of my talk was how different forms of radiation can affect electronic components and systems. As part of this, I purchased a medium-sized pseudo-antique suitcase to use as a 'stage prop' (think Harry Potter, or the movie *Fantastic Beasts and Where to Find Them*). I equipped this case with retro switches and indicators, and packed it full of electronics. Apart from anything else, this resulted in some interesting experiences with airport security, but that's a tale for another day.

The reason I mention this here is that my purchase included a smaller antique-looking valise, which has been lurking around my office for years, and which I determined to use as the basis for an audio-reactive artifact – see Fig.1. I also have a copious collection of old, defunct vacuum tubes that I've been hanging onto

in the hope that they would prove useful, so the first thing I did was to gather a representative sample, arrayed in Fig.2.

A perfect presentation

Next, I cut out a piece of card the same size as the inside of the case and I played around with different combinations of tubes until I settled on one that pleased me. My idea is to have the tubes organised larger-to-smaller from left-to-right and from back-to-front. I also presented them in three groups to represent the base (left), middle (middle) and treble (right) frequencies.

Once I was satisfied with my layout and had marked the tube sizes and positions on the card, I cut a piece of ¼-inch plywood to the same size, transferred the tube positions over, drilled the holes, painted it black, and attached the tubes using clear two-part epoxy. See Fig.3.

A tangle of wires

While I was pondering the electronics, I set about wiring up my tri-coloured LEDs, which come in the form of WS2812-based NeoPixels from Adafruit. To accommodate the different sized tubes, I'm using one 16-element ring (<https://bit.ly/2oL6R3m>), one 12-element ring (<https://bit.ly/2DxA2xi>), thirteen 7-element 'jewels' (<https://bit.ly/2AycJSa>), and a bunch of individual NeoPixels cut from a 60-pixel-per-meter strip (<https://bit.ly/2RC2s2q>).

To aid in the wiring process, I used the wooden panel with the holes as a template. I flipped it over to reflect the



Fig.3. All of the selected vacuum tubes sorted and mounted in black-painted plywood in the antique valise.

view from the underside (I did this before gluing the tubes in, of course), and traced the holes onto a new piece of card. Then I attached the NeoPixels to the card with painter's masking tape and started to wire everything together. I thought this part was going to be easy, but it actually it took much longer than I expected; in fact, I'm still not quite finished (Fig.4).

Lucky seven

Apropos of nothing at all, humans have been interested in the properties of odd numbers since antiquity, often ascribing mystical and magical properties to them; for example, 'lucky seven' and 'unlucky thirteen.' As Pliny the Elder (AD 23-79) is reported to have said, 'Why is it that we entertain the belief that for every purpose odd numbers are the most effectual?'

I mention this because I want you to imagine we'll use our MCU to drive seven groups/strings of LEDs (as in Fig.5). Since we are working with NeoPixels that can be daisy-chained together and individually controlled, we can actually drive hundreds of these lights using a single MCU pin, but visualising them as seven groups helps clarify the following discussions.

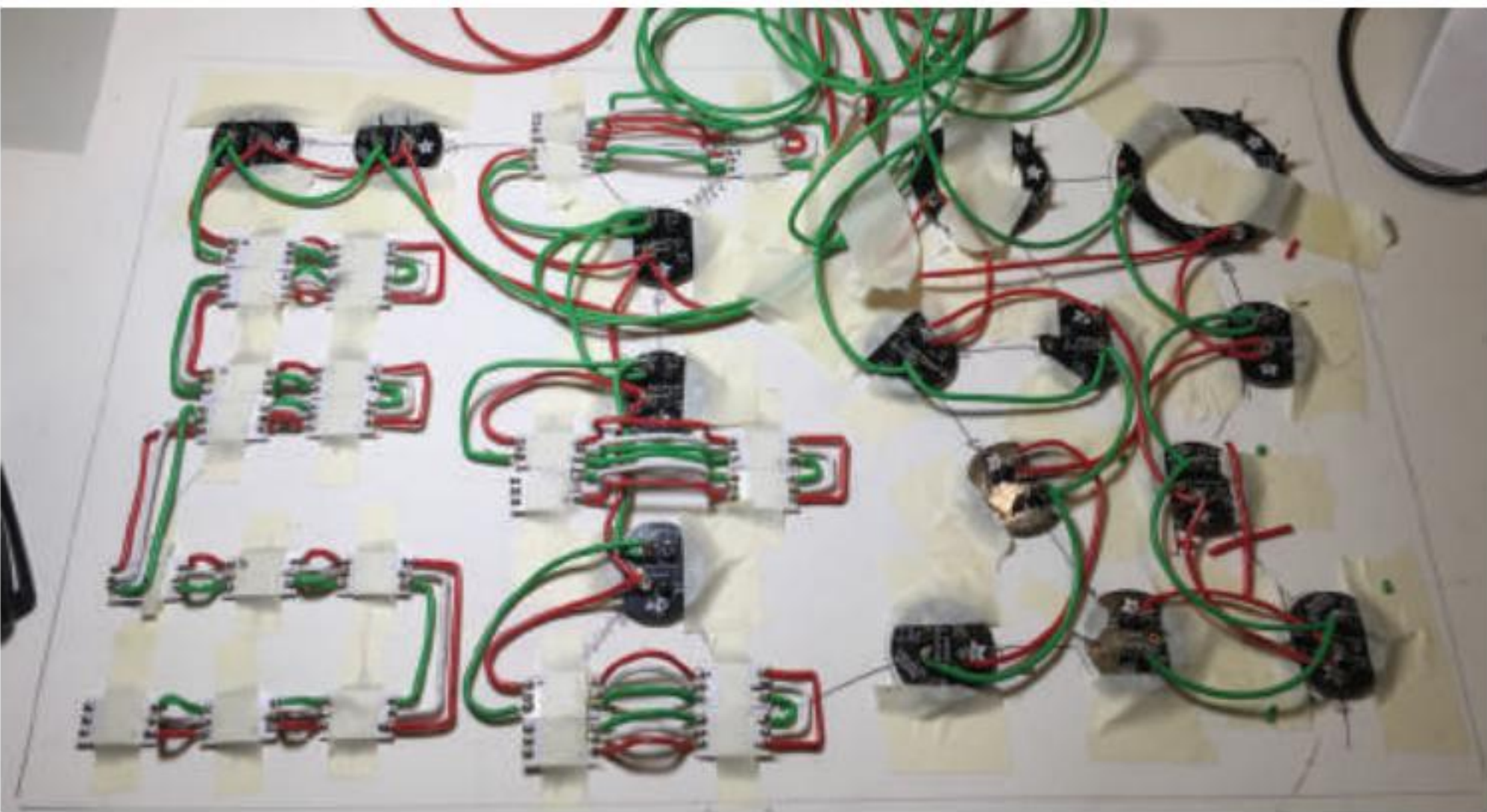


Fig.4. Wiring the pixels under the vacuum tubes.

Decisions, decisions...

The next step is to decide how we wish to capture our audio signal and use it to control our LEDs. A really good solution for projects of this type is a MEMS electret microphone mounted with an associated amplifier presented on a small breakout board (BOB). However, each BOB typically has its own characteristics, so you have to pick one that matches what you are trying to do.

One possibility would be to connect the audio output from the microphone BOB directly to one of our MCU's analogue inputs. In this case, assuming we are using a 5V Arduino Uno, for example, we would prefer a BOB with a 2.5V DC bias and a 5Vpp (peak-to-peak) voltage swing, like the MAX4466 with adjustable gain from Adafruit (<https://bit.ly/2svzouV>).

At the moment, the only information we can extract from this signal is its current amplitude every time we sample it; but, we could use this information in a variety of ways. For example, we could drive all of our LEDs with the same colour but vary their brightness to reflect the amplitude, or we could use different groups of LEDs and/or different colours to reflect different amplitudes, or... we are limited only by our imaginations.

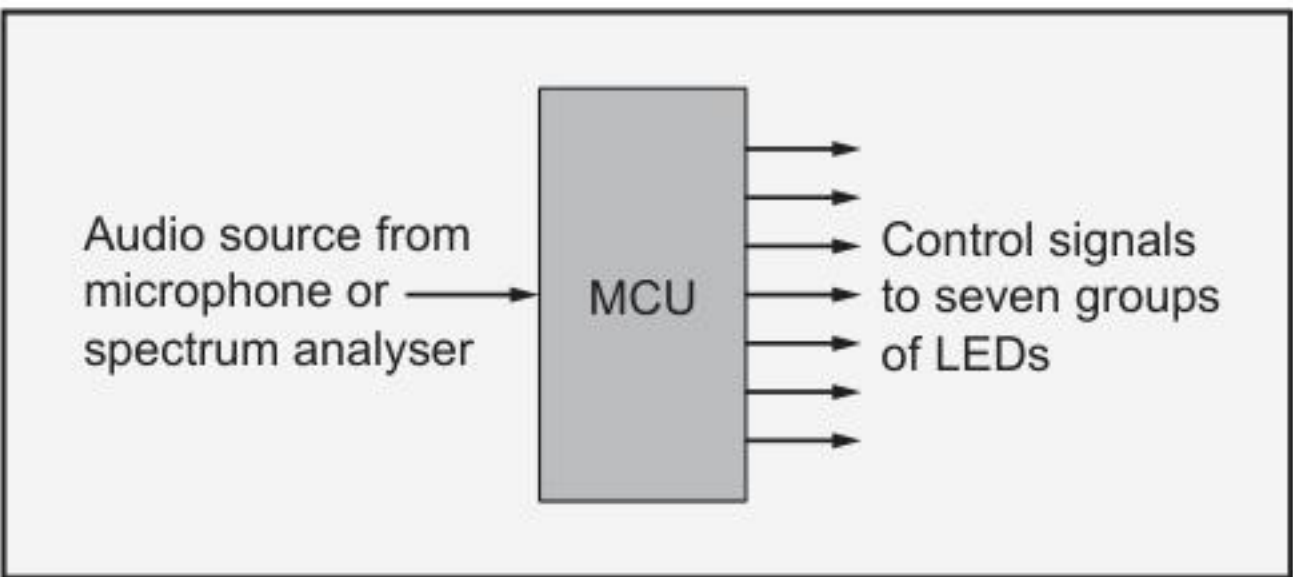


Fig.5. Seven groups of LEDs

Now, the normal range of human hearing covers the range from 20 to 20,000Hz, although we tend to lose the ability to detect the higher frequencies over the years (it makes me sad to think I may be missing things when I listen to my favorite music). Anyhoo, another alternative is to split our audio signal into some number of frequency bands. Let's say we decide to use seven overlapping bands centered on 63Hz, 160Hz, 400Hz, 1,000Hz, 2,500Hz, 6,250Hz, and 16,000Hz (Fig.6), for example.

One way to do this would be to employ an algorithm called an FFT (Fast Fourier Transform), which we can use to transform our audio signal in the time domain into its components in the frequency domain. Let's assume we are using an Arduino Uno as our MCU. If you search around the Internet, you can find a variety of FFT libraries for the Arduino. The only problem is that an FFT is a compute-intensive algorithm, which means we won't have much compute-resource left over for anything else.

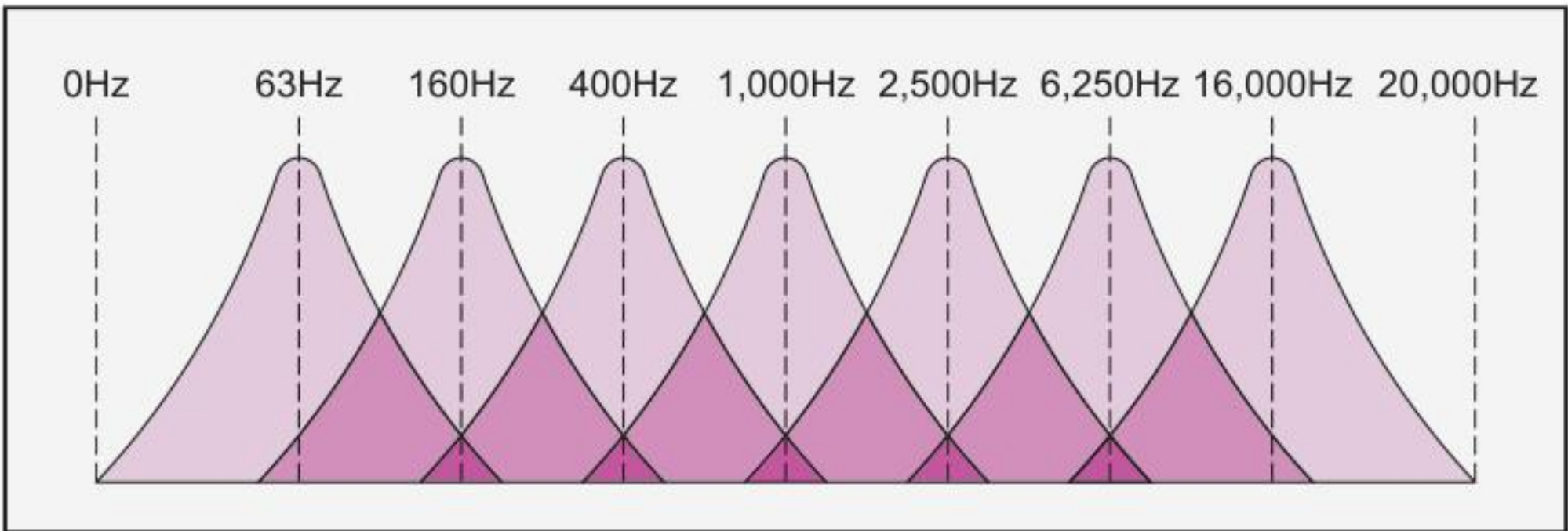


Fig.6. Seven overlapping frequency bands used to drive the LEDs.

Ah ha! The MSGEQ7!

A great option that I use a lot is the 8-pin MSGEQ7 spectrum analyser device – see Fig.7. You can pick these little scamps up as standalone components from SparkFun (<https://bit.ly/1jRKv3C>), or you can purchase pre-constructed breakout boards from SparkFun or on eBay.

In this case, all you have to do is feed the audio signal from your microphone BOB into your MSGEQ7 BOB, and the MSGEQ7 automatically splits this signal into the seven frequency bands discussed above. Now you can use your MCU to read the amplitude of each frequency band from the MSGEQ7, after which it's up to you to decide how you wish to use this information to drive your LEDs.

One consideration is that the MSGEQ7 only requires an audio input with a 0.3Vpp (300mVpp) swing. In this case, one MEMS microphone BOB that works well with the MSGEQ7 is the INMP401 from SparkFun (<https://bit.ly/1RdKnR3>).

Now, you have to be careful here, because the official MSGEQ7 data sheet (<https://bit.ly/2RcN90I>) can be a little hard to interpret even on a good day, plus it contains a couple of 'gotchas' that can really make your head ache. There are too many nitty-gritty details for us to cover here. Fortunately, I've written a column, *Tips and Tricks for Using the MSGEQ7*

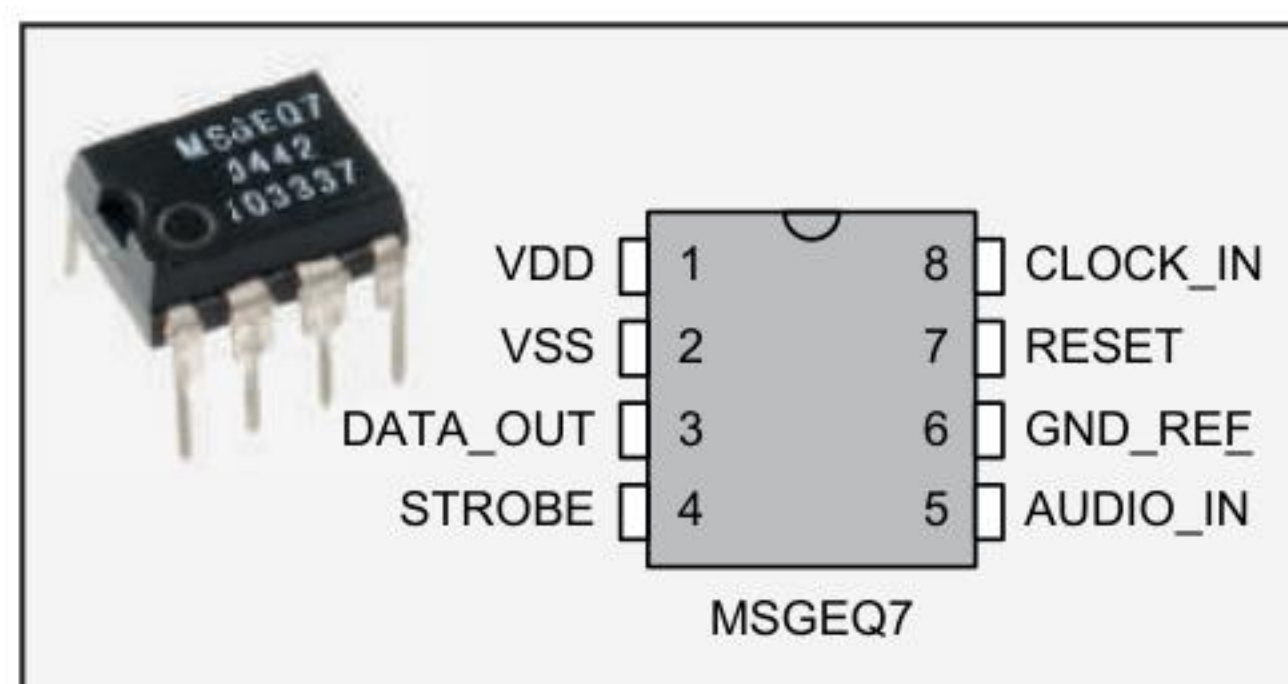


Fig.7. The clever MSGEQ7 IC.

Spectrum Analyzer that covers all of this in excruciating detail over on my **EEWeb.com** website (<https://bit.ly/2sbiXUV>).

Seven to three

Do you recall earlier in this column when I was talking about my current audio-reactive project and I noted that I presented my LED-lit vacuum tubes in three groups to represent the base (left), middle (middle) and treble (right) frequencies? Well, as we just discussed, the MSGEQ7 splits the audio signal into seven bands, which we might number 0 through 6.

What we could do is group the two lowest bands (0 and 1) together to drive our base LEDs, the two highest bands

(5 and 6) to drive our treble LEDs, and the three middle bands (2, 3, and 4) to drive our middle LEDs. But how are we to do this? Take the middle bands, for example; should we add the values from bands 2, 3, and 4 together and divide by 3 to get the average, or should we just use whichever has the highest amplitude?

Another consideration is how we drive the LEDs in our three groups. Do we drive all of the LEDs in one group with the same colour and vary their intensity to reflect the amplitude of that group, or do always drive the LEDs full on but vary their colour to reflect the amplitude? Another alternative would be to always drive the LEDs full on, but to light up different rows of tubes forming the group to reflect the amplitude. And these are only a smattering of the possibilities.

As soon as I finish wiring my LEDs, I'm going to start experimenting with different microphone BOBs and different lighting effects. I will take a video of this little scamp when it's up and running, and I will report further in a future column.



Cool bean Max Maxfield (Hawaiian shirt, on the right) is editor-in-chief at **EEWeb.com** – the go-to site for users of electronic design tools and askers of electronic questions.

Comments or questions? Email Max at: max@CliveMaxfield.com



Teach-In 8 Exploring the Arduino

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 provides a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project. The projects can be combined together in many different ways in order to build more complex systems that can be used to solve a wide variety of home automation and environmental monitoring problems. To this end the series includes topics such as RF technology, wireless networking and remote Web access.

PLUS: PICs and the PICkit 3 – A beginners guide

The why and how to build PIC-based projects. An extra 12-part series based around the popular PIC microcontroller.

FREE COVER-MOUNTED CD-ROM

Containing the software for the two series



PRICE

£8.99

(includes P&P to UK if ordered direct from us)

**ORDER YOUR COPY TODAY JUST CALL
01202 880299 OR VISIT www.epemag.com**

Last month, we described options for deriving low-level power supplies in audio systems using a power amplifier's power supply. This month, we'll describe and build a universal audio power supply for low-level circuitry, which uses a dedicated transformer/rectifier.

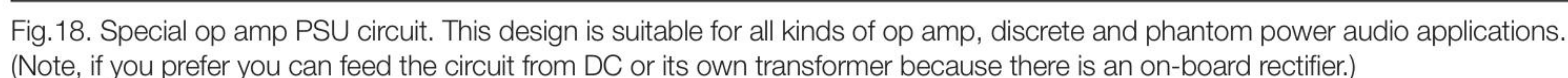
low-level circuitry, which I use in several audio/music products. It can be fed directly from suitable transformers or a power amplifier power supply with suitable adaptation.

This design is also useful for constructors who need to convert a single-rail

bench supply to a dual version. It uses the audio industry's favourite regulator: the cheap, low-noise LM317, which with a few strategically placed Zener diodes can be coerced into tolerating high input voltages.

The general circuit covering all options is shown in Fig.18. There is the usual provision for a bridge rectifier D1 to D4, which can be made up using Schottky devices for low RF noise if desired (essential for AM radios and Theremins). These diodes also minimise voltage drop. This may be necessary if the transformer voltage and resulting regulator headroom is a bit low. SB60s are a good choice to replace ordinary 1N4003 diodes. A two-stage smoothing filter is provided (C3, C4 and R1) which reduces the high-frequency harmonics that regulators find more difficult to filter due to their diminishing open-loop gain at HF.

A lot of additional information relating to the layout of power supply PCBs was covered in *Audio Out*, December 2016, and I recommend having



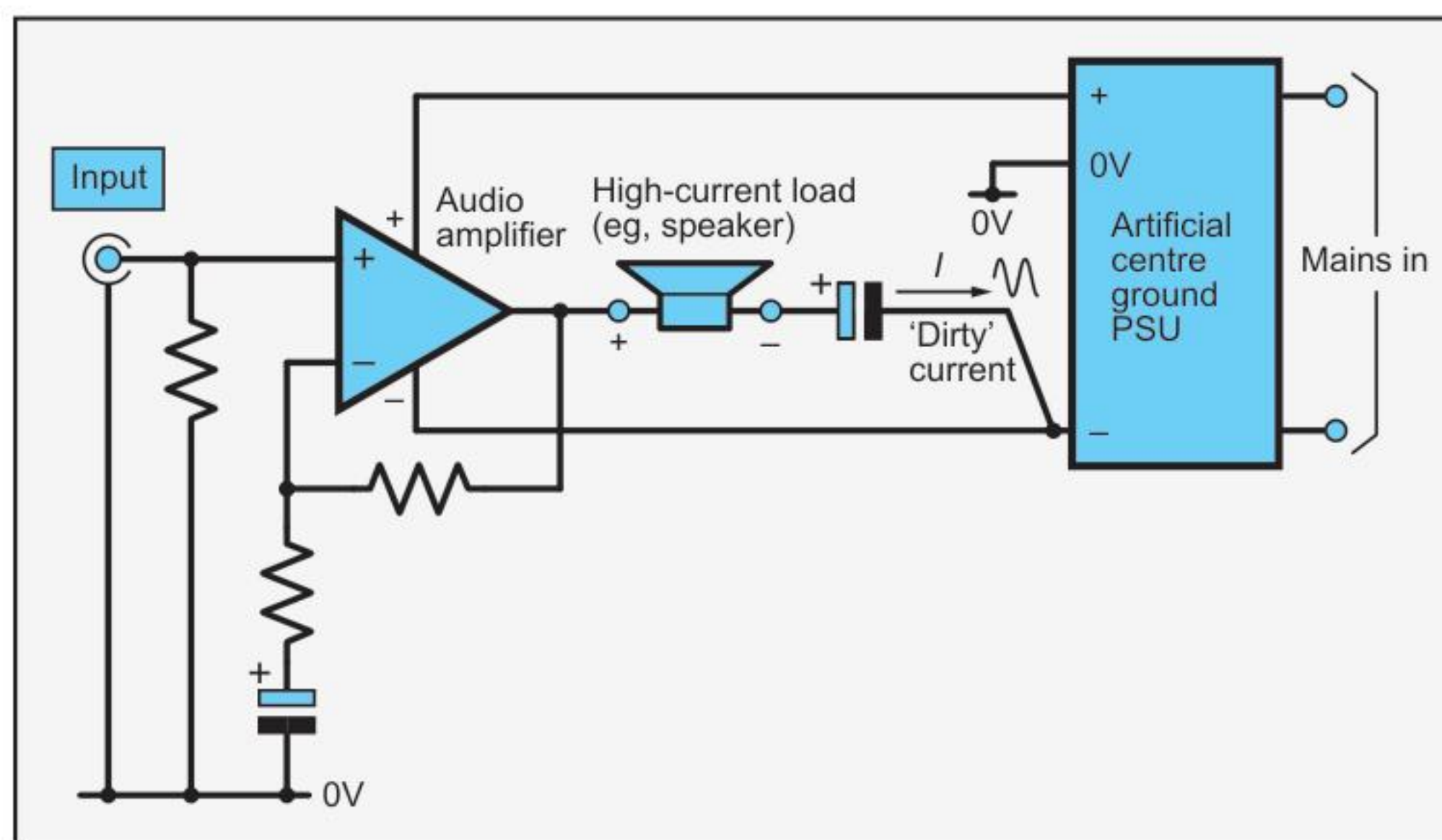


Fig.19. Avoid feeding significant currents into the artificial ground. Feed them into the negative rail via an electrolytic capacitor. To avoid the issue of the regulator's 0V reference being the negative rail I sometimes try connecting it to the artificial ground instead.

a reread of that article. In this design, the output can be calculated using:

$$V_{out} = 1.25 \times (1 + R5/R7)$$

For 30V ($\pm 15V$) use $R5 = 2.7k\Omega$ and $R7 = 120\Omega$. It is sensible to allow 2V headroom under worst-case conditions between the DC input voltage and regulated output voltage.

There is a dual op amp (IC2) buffering an equal-value decoupled potential divider (R9 and R10) to provide a centre-rail or simulated ground point, which enables the circuit to provide a dual-rail output from a single secondary transformer. This saves money, and it also means a standard AC 'wall-wart' can be used. The caveat with artificial grounds is that the ground current is limited by what the op amp can handle. In a normal dual supply it can be as high as the rails will permit, but in this case the limit is about 80mA for a NE5532. That should be sufficient, since good audio designers try not to put currents into the ground, because current flowing through any non-zero impedance will result in the ground being raised above zero volts, resulting in clicks and distortion. Of course some loads, such as loudspeakers or output transformers, normally put significant AC current to ground. With such loads, the lower terminal should be taken to the negative rail via an electrolytic capacitor, as shown in Fig.19. This is necessary because the DC reference 0V for

the regulator in this type of system is the negative rail, not the 0V rail. Failure to do this could result in the power rails jumping about with the music relative to the artificial ground.

Provision has been made on the PCB for a small inductor (L1) in series with the output to prevent instability with decoupling capacitors C7 and C8. In fact, you are unlikely to need this – it can be linked out. I have only ever needed to use it once with some ultra-low ESR polymer capacitors. Note that C7 and C8 should be rated at the full regulator output, not the half-rail output. This is necessary, because if one rail is shorted to the artificial ground, the full voltage will appear across the capacitor on the other rail.

Multiple versions

Normally, if the input to the regulator is below 37V under all conditions, overvoltage protection won't be required. In this case D5 and D6 can be ordinary 1N4003 diodes, which provide capacitor discharge paths. However, some op amps (eg, NE5532 or LF356) may need to be powered up to $\pm 21V$ rails for maximum headroom. Thus, IC2, the buffer amplifier must be rated at a maximum rail voltage of $\pm 22V$. The regulator itself must be able to output 42V to achieve the $\pm 21V$. This is in excess of its maximum 35V output or 37V input (allowing for 2V headroom to prevent drop out). To get round this restriction, Zener protection diodes are used across the regulator's input to output (D6) and adjust pin to output (D5). This enables the output of the regulator to be raised up to 48V, suitable for microphone phantom power and high headroom pre-amplifier power supplies, such as the one I described in Fig.25, *Audio Out*, April 2016. Note the resistors (R15 and R16) in series with the diodes to protect them from high surge currents if the output is short circuited. On the PCB they are linked out if 1N4003 diodes are used. The Zeners also provide a discharge path for capacitors when the circuit is powered down. Remember, Zener diodes behave like a normal diode when forward biased, albeit with a slightly higher forward voltage of around 0.72V.

There is a current-limiter circuit built into the negative output of the bridge rectifier stage. The voltage drop across R3 turns on TR1 and pulls down the reference voltage of the regulator if the short-circuit current is exceeded. This is set by R3 for 0.6V to turn on the transistor. For example, if $R3 = 6.2\Omega$ the short circuit current will be 100mA. R4 needs to be double the value of R3 to compensate for the 1.2V voltage on the adjust pin. The transistor circuit works for the lower

input voltage range ($< 37V$). For higher voltages, a Polyswitch should be inserted, although they are more expensive. This is because the transistor circuit can't be used if a Zener is used for D5 because a massive current will flow down to earth through TR1. It's not a good idea to have the short-circuit protection transistor fail if shorted! Without short-circuit protection, the current limit is set by the high default 1.5A limit of the LM317 – or whatever blows up first.

The screwdriver test

I'm afraid I'm a brutal designer. I crowbar my power supply and amplifier outputs with screwdrivers to check that they can withstand short circuits. If you don't do it, you can guarantee a drunk musician or roadie will. Of course, there is subtlety with audio design as well. There is a slow turn-on circuit built around TR2. This reduces noises on turn-on and protects tantalum capacitors and semiconductors from damaging surge

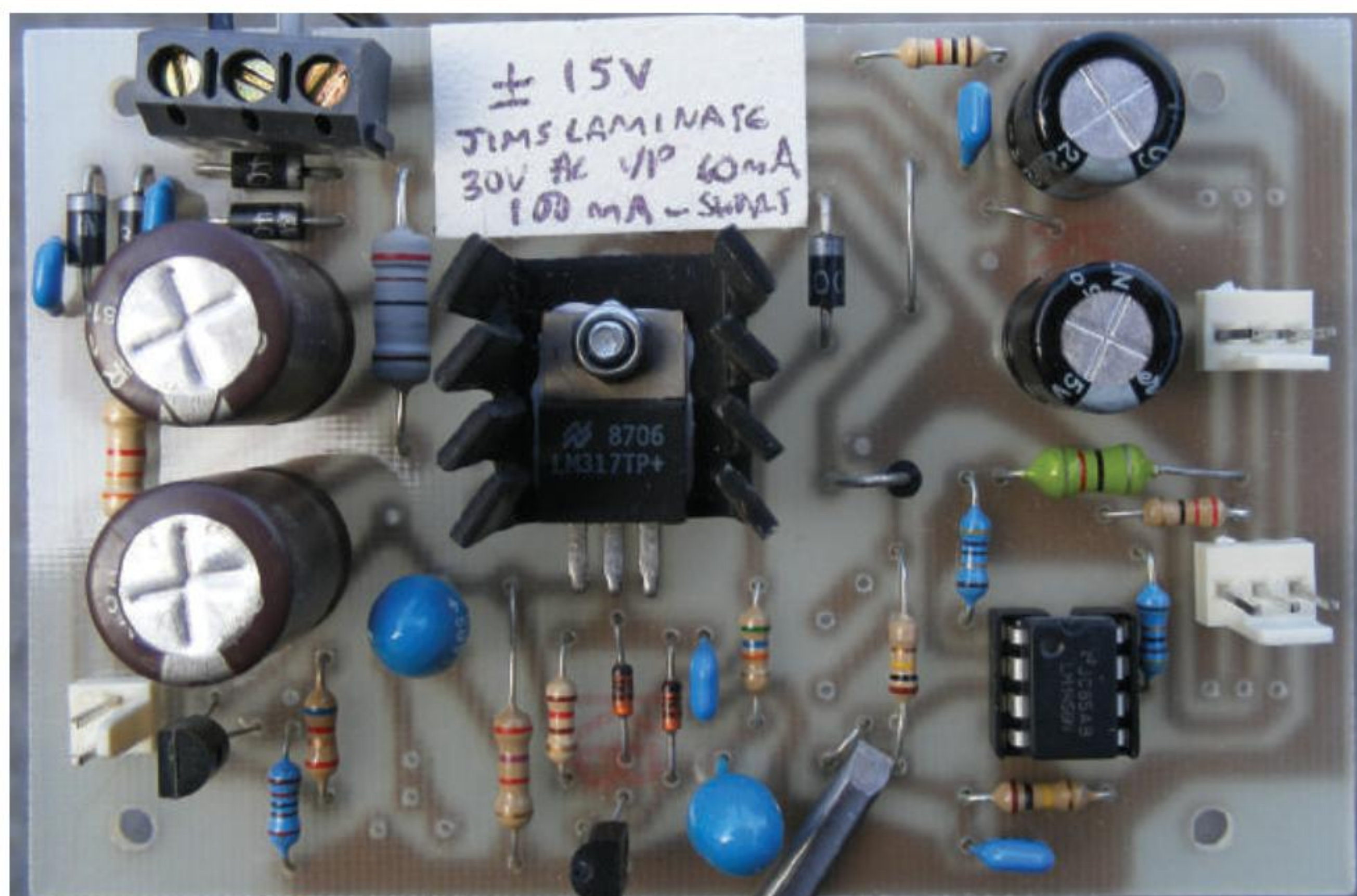


Fig.20. The standard $\pm 15V$ version of the low-level supply. The low-current limit of 100mA protects your op amps.

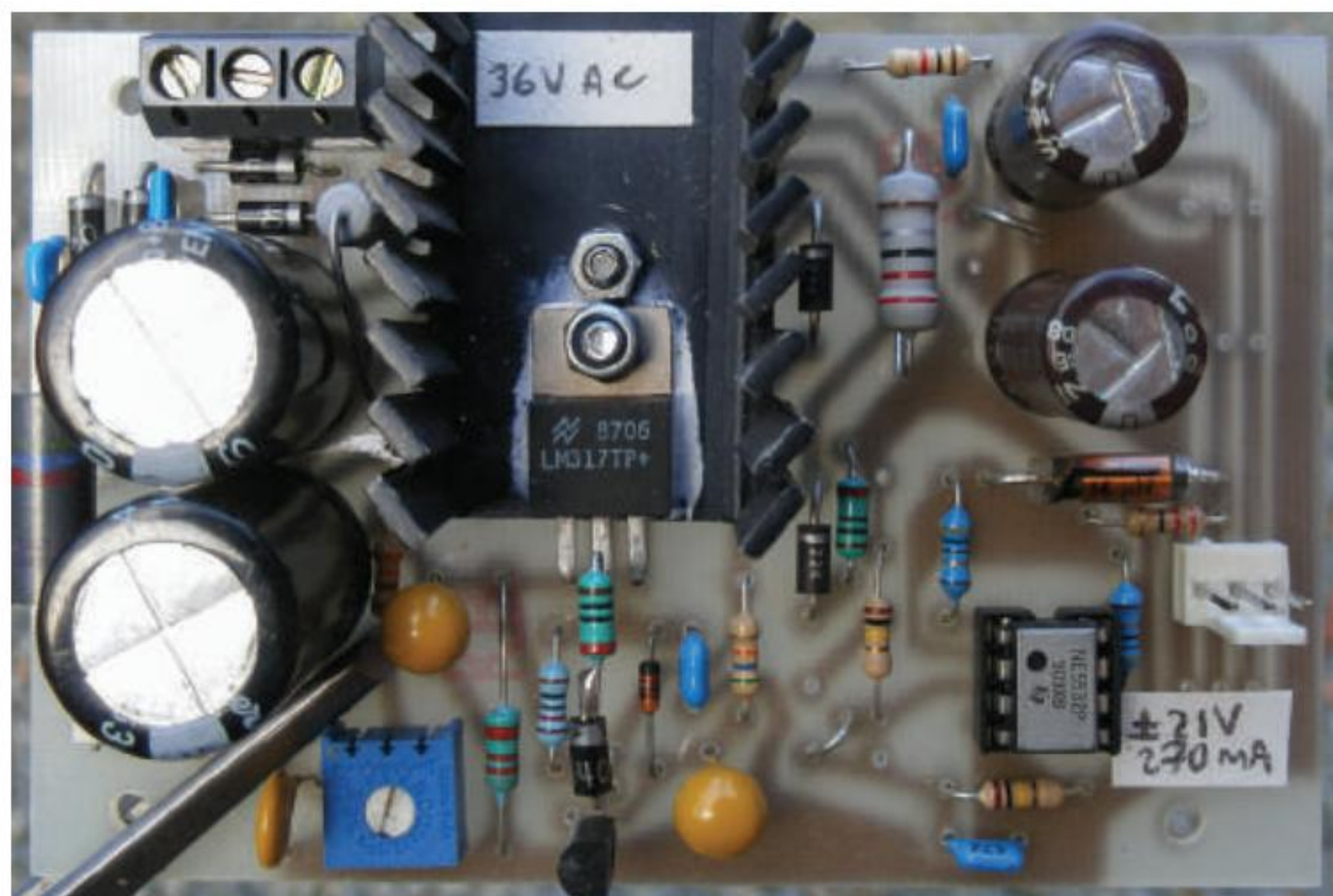


Fig.21. $\pm 21\text{V}$ 280mA version for high quality NE5532-op-amp-based audio. Please note in the above photo I have added an extra 10Ω resistor in series with D7 to the regulator centre pin to protect C4 – an nice, but optional addition.



Fig.22. Single-rail 48V low-current version for microphone phantom power. This design omits the centre-rail generator circuitry. The high output voltage requires Zeners and resistors for protection. Note link for single-rail operation (upper right) and PTC (lower left).

currents in the circuit to be powered. Feel free to omit these optional refinements and modify the PCB layout for your own needs. Fig.20 to 22 show three common versions I use. It's possible

to do all sorts of other configurations with a bit of linking and imagination. Be very careful to select the right components and links for the version you build. I know I'm being patronising to

experienced constructors, but multi-version PCBs can be a recipe for errors. The suggested standard $\pm 15\text{V}$ 100mA circuit board is shown in Fig.20 using a small 28V transformer. The high voltage $\pm 21\text{V}$ 280mA version using a standard 18-0-18V toroid is shown in Fig.21, and finally, the single-rail 48V 65mA in Fig.22. A general PCB overlay and track layout is given in Fig.23. I've had 100 of these boards made by Chiltern Circuits, and I'm happy to supply readers if required – just email me at: jacob.rothman@homecall.co.uk

Construction tips

There are two holes on the board for two different sizes of heatsinks. The bigger 9.9°C/W and the smaller 21°C/W . Use an M3 bolt, spring washer and thermal compound to mount the LM317. Fully tighten, *then* solder it. This order is to prevent the joints from cracking. The smoothing capacitors and some of the resistors have extra holes to accommodate larger sizes. Provision is also made on the board for optional presets to adjust voltage (PR1) and centre-rail symmetry (PR2). These are unlikely to be needed except for experimenting with prototypes. Note that if fixed resistors are used, PR1 is omitted and PR2 linked.

Ground lift

R14 and C9 provide ground lift to prevent earth loops and to tie the mains earth to the signal earth. C9 provides an RF bypass. There is a link on the board to allow the ground connection to be made to the artificial ground for dual-rail use. If the board is being used for single-rail operation, the link is moved to connect it to the negative rail – see PCB overlay. The mains earth and transformer AC connections are made via a 3-way screw terminal block. There are four DC outputs available on 3-way Molex connectors.

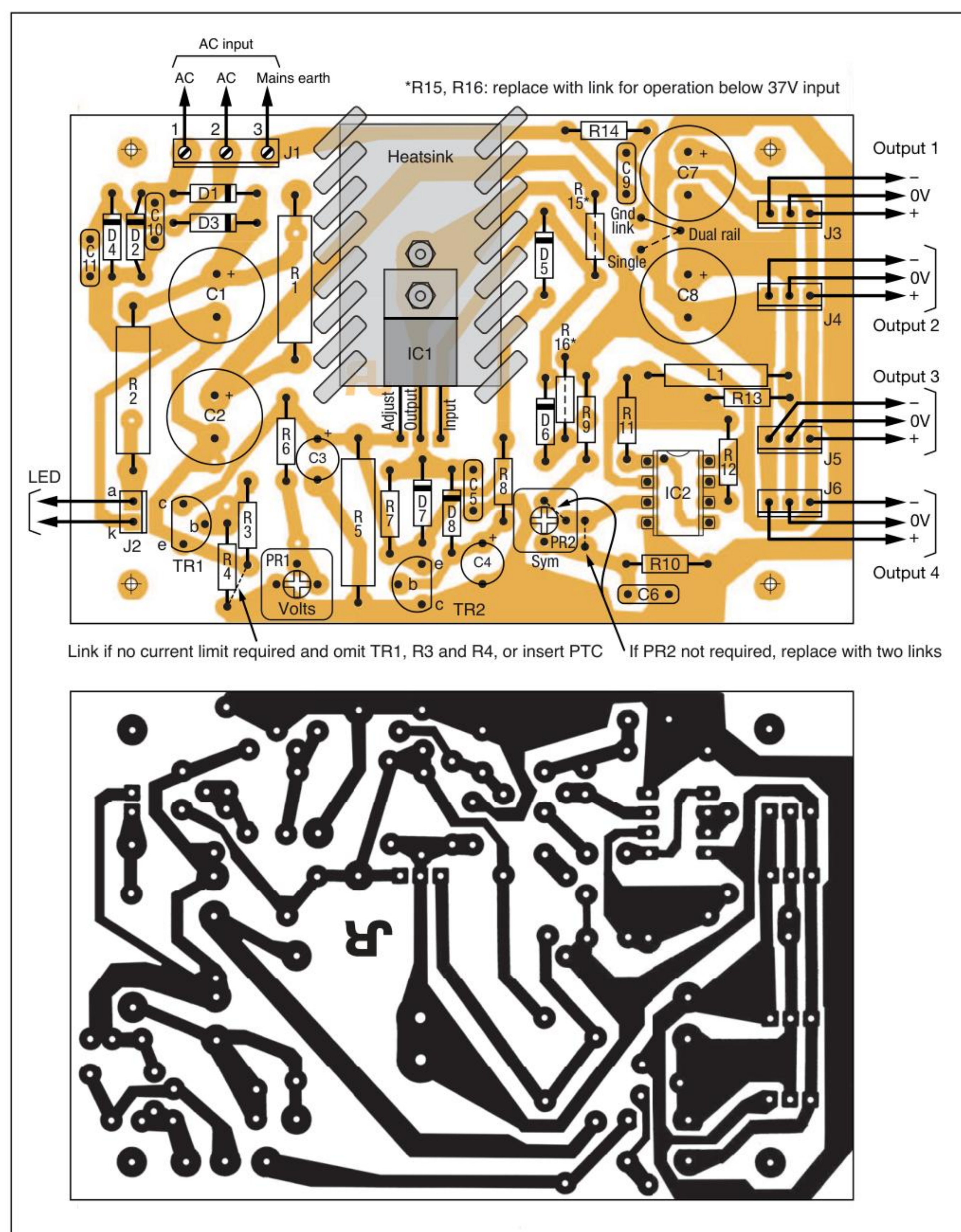


Fig.23. The PCB overlay and track layout. No spindly CAD here, just thick tape! The design is available on the *EPE* website.

Parts list – Universal Audio Power Supply

The unbracketed values are for the standard $\pm 15\text{V}$ 100mA version. **The values in brackets are the high-voltage $\pm 21\text{V}$ 280mA version.** The single-rail 48V 65mA version omits IC2 and its associated centre-rail parts.

PCB

Available from me or the the design can be downloaded from the *EPE* website

Resistors

All 5% 0.25W unless otherwise stated; all 1% are metal film.

R1 2.2 Ω 2.5W wire wound

R2 3.3k Ω 1W (5.6k Ω 1W) (9.1k Ω 1W 48V version)

R3 6.2 Ω (not high-voltage version)

R4 12 Ω (not high-voltage version)

R5 2.7k Ω 0.5W (8.2k Ω 0.6W high-voltage version) (9.1k Ω 0.6W for 48V version)

R6 not used (3.3k Ω high-voltage version) (6.2k Ω for 48V version)

R7 120 Ω 0.25W 1%

R8 56k Ω

R9, R10 100k Ω 0.25W 1%

R11, R12 47 Ω

R13 22 Ω , optional, normally a link

R14 1k Ω

R15 link (2.2 Ω 2.5W wire wound) (10 Ω 0.5W 48V version)

R16 link (10 Ω for high-voltage and 48V version)

PR1 not used in low-voltage version (10k Ω Bourns 3386 or equiv. for high-voltage version) (5k Ω for 48V version)

PR2 100k Ω optional

Capacitors

470nF and below are ceramic, all electrolytic capacitors are radial

C1, C2 1000 to 2200 μF , 50 $\pm 15\text{V}$ (1000 μF 63V) (48V 65mA version 220 μF 100V)

C3 10 to 100 μF 50V

C4 10 μF 50V

C5, C6 470nF (10 μF 63V on 48V version)

C7, C8 470 μF 25V (220 μF 50V)

C9 10nF

C10, C11 100nF

Inductor

L1 10 μH to 15 μH – optional, normally just a link

Semiconductors

IC1 LM317T

IC2 LM1458 (NE5532)

D1 to D4 1N4002 or SB40, (1N4004)

D5, D6 1N4001 (24V 2W ZY24 or equivalent Zener diode)

D7 1N4002

D8 1N4148

TR1 BC337 (not for high-voltage version)

TR2 BC327 optional slow turn on

Suitable transformers

Wye Winding 43-0-43V + 8-0-8V, 80mA wired for a total of 51V; available from author, or a 24-0-24V transformer rated at or above 15VA.

JIM Electronics 28V, 140mA for the $\pm 15\text{V}$ standard op amp version – available from author; or a 25V, 15VA transformer.

18-0-18V 15VA torroid for $\pm 21\text{V}$, 280mA version

Heatsink

TO220 twisted vane 21°C/W Aavid Thermalloy TV4; Farnell 107-075, or Aavid Thermalloy TV40G 9.9°C/W; Farnell 170-074 for $\pm 21\text{V}$ version

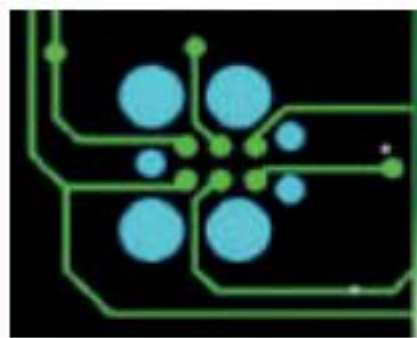
Connectors

3-terminal 3A screw connector; Rapid 21-0442

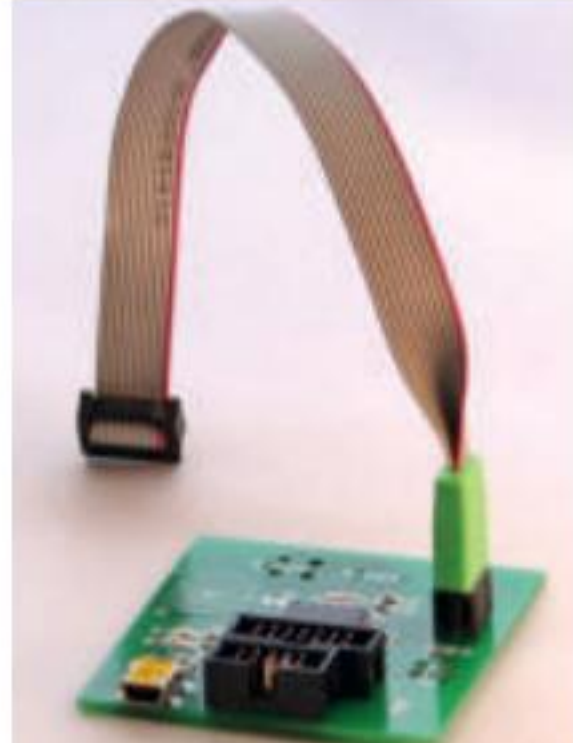
3-way Molex headers, 4 off; Rapid 22-0955

Miscellaneous

Polyswitch 0.5A XF050; Rapid 26-0720 (48V version, XF017 170mA; Rapid 26-0840)



Tag-Connect



JTAG Connector Plugs Directly into PCB!!

No Header! No Brainer!



Our patented range of Plug-of-Nails™ spring-pin cables plug directly into a tiny footprint of pads and locating holes in your PCB, eliminating the need for a mating header. **Save Cost & Space on Every PCB!!**

Solutions for: PIC . dsPIC . ARM . MSP430 . Atmel . Generic JTAG . Altera Xilinx . BDM . C2000 . SPY-BI-WIRE . SPI / IIC . Altium Mini-HDMI . & More

www.PlugOfNails.com

Tag-Connector footprints as small as 0.02 sq. inch (0.13 sq cm)

ESR Electronic Components Ltd





All of our stock is RoHS compliant and CE approved. Visit our well stocked shop for all of your requirements or order on-line.

We can help and advise with your enquiry, from design to construction.

3D Printing • Cable • CCTV • Connectors • Components • Enclosures • Fans • Fuses • Hardware • Lamps • LED's • Leads • Loudspeakers • Panel Meters • PCB Production • Power Supplies • Relays • Resistors • Semiconductors • Soldering Irons • Switches • Test Equipment • Transformers and so much more...

Monday to Friday 08:30 - 17.00, Saturday 08:30 - 15:30





**Station Road
Cullercoats
North Shields
Tyne & Wear
NE30 4PQ**

Tel: 0191 2514363 sales@esr.co.uk www.esr.co.uk

MOSFET power switches – Part 1

This month's topic – MOSFET power switches, with a little bit of Zener regulation thrown in – is based on a post by Michael Ferguson on the EEWab forum (www.eeweb.com/forum). In his post, Michael wrote the following.

'I'm working on the circuit in the attached image [redrawn in Fig.1]. I've quickly realised there is not any good way to activate the V_{gs} of my power MOSFET with my gate driver. I've looked online at some other gate drivers, and all of them only output low voltages around 20-30V max.

Every single datasheet for gate drivers intended to be used with power MOSFETs describes their output in terms of current. Sink or source, up to 4A / 6A, etc.

These are two of the gate drivers that I have [UCC20520 from Texas Instruments and ISL55110 from Renesas], one of them is also an isolated gate driver, specifically used for power MOSFETs.

I understand that the MOSFET gates activate upon charging to a certain Q_g , but if the gate voltage needs to be 10V > than V_s , and V_s is 200V+, how is it possible to turn the gate on and let current flow from V_s to V_D ?

We will introduce some MOSFET basics this month, followed by switching circuits

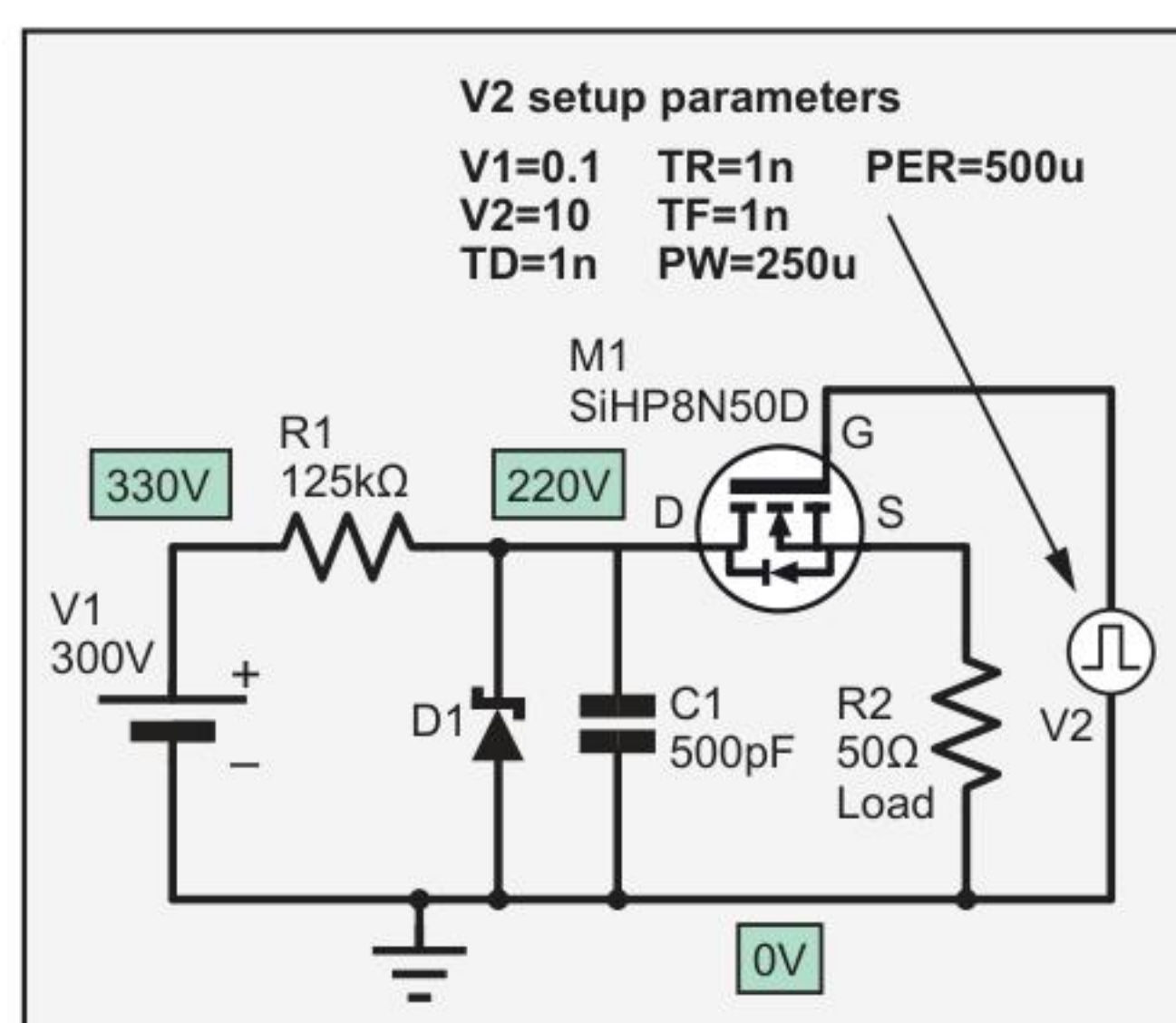


Fig.1. Michael's circuit, redrawn from his EEWab post.

Simulation files

The LTSpice files discussed in *Circuit Surgery* are available for download from the *EPE* website.

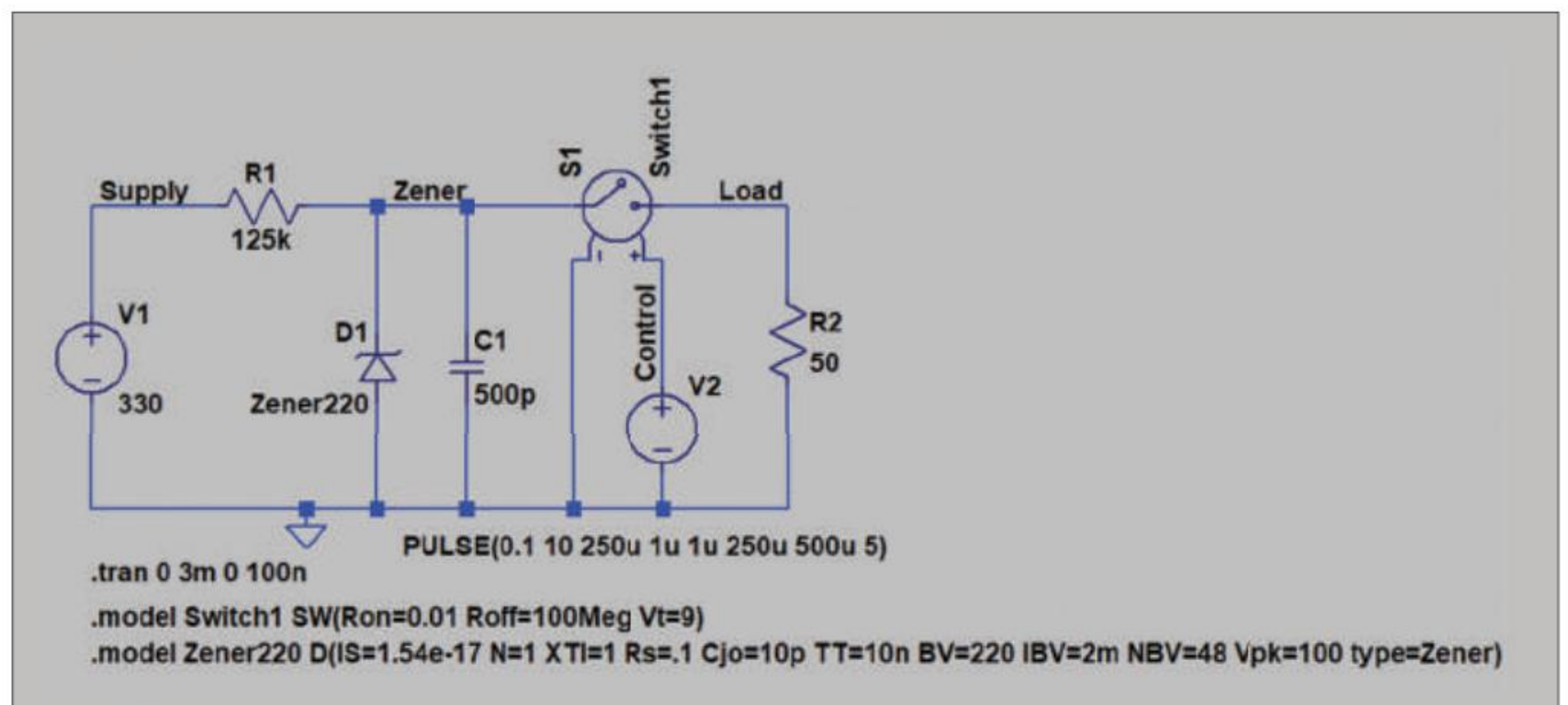


Fig.2. Schematic for LTSpice simulation of Fig.1 with an idealised switch instead of the MOSFET.

and MOSFET drivers in more detail next month. However, before looking at MOSFETs we will address an issue with the Zener regulation in the circuit in Fig.1, for which we need to make some assumptions about the requirements for the load switching. Although Michael's post does not fully specify the load he wants to switch, we will assume from what he wrote, and from the schematic, that the applied voltage is 220V and the load resistance is 50Ω. This implies a current of 4.4A ($=220V/50\Omega$). The MOSFET in Fig.1, the SiHP8N50D, an N-channel D-Series Power MOSFET from Vishay (www.vishay.com), has a maximum allowable drain current of 8.7A at a case temperature of 25°C, reducing to 5.5A at 100°C. Its maximum drain-source voltage is 500V. This appears to match our assumed load requirements.

The problem with the circuit in Fig.1 is that it cannot deliver anywhere near 220V at 4.4A to the load (R_2), even with an

Insufficient drive

ideal switch in

place of the MOSFET. The 220V is obtained by a Zener regulator (R_1 and D_1) from a 330V source (we assume the Zener is 220V from the voltage annotation on the schematic). R_1 limits the current to the load – if we short the 220V line to ground the current in R_1 is 2.64mA ($330V / 125k\Omega$). The load current cannot exceed this. Looking at this another way, if we assume the MOSFET is an ideal switch, then, when it is on, R_1 and R_2 form a potential divider across the 330V supply. The resulting voltage across the load, using the potential divider formula, is: $R_2 \times V_2 / (R_1 + R_2) = 50\Omega \times 330V / (125k\Omega + 50\Omega) = 132mV$. This is well below 220V because the current of around 2.6mA is

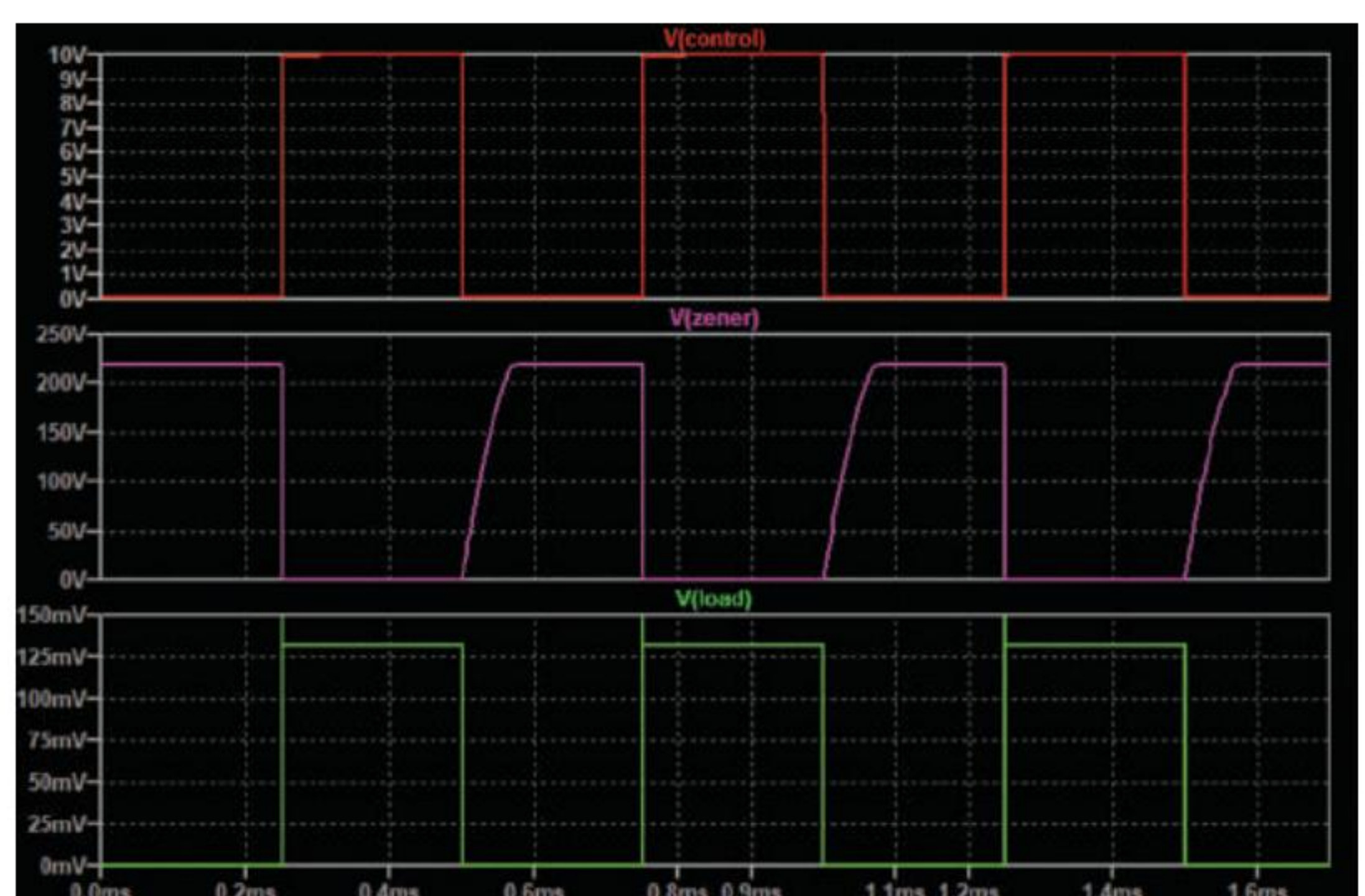


Fig.3. Simulation results from the circuit in Fig.2 – Top: V(control); middle: V(zener); bottom: V(load).

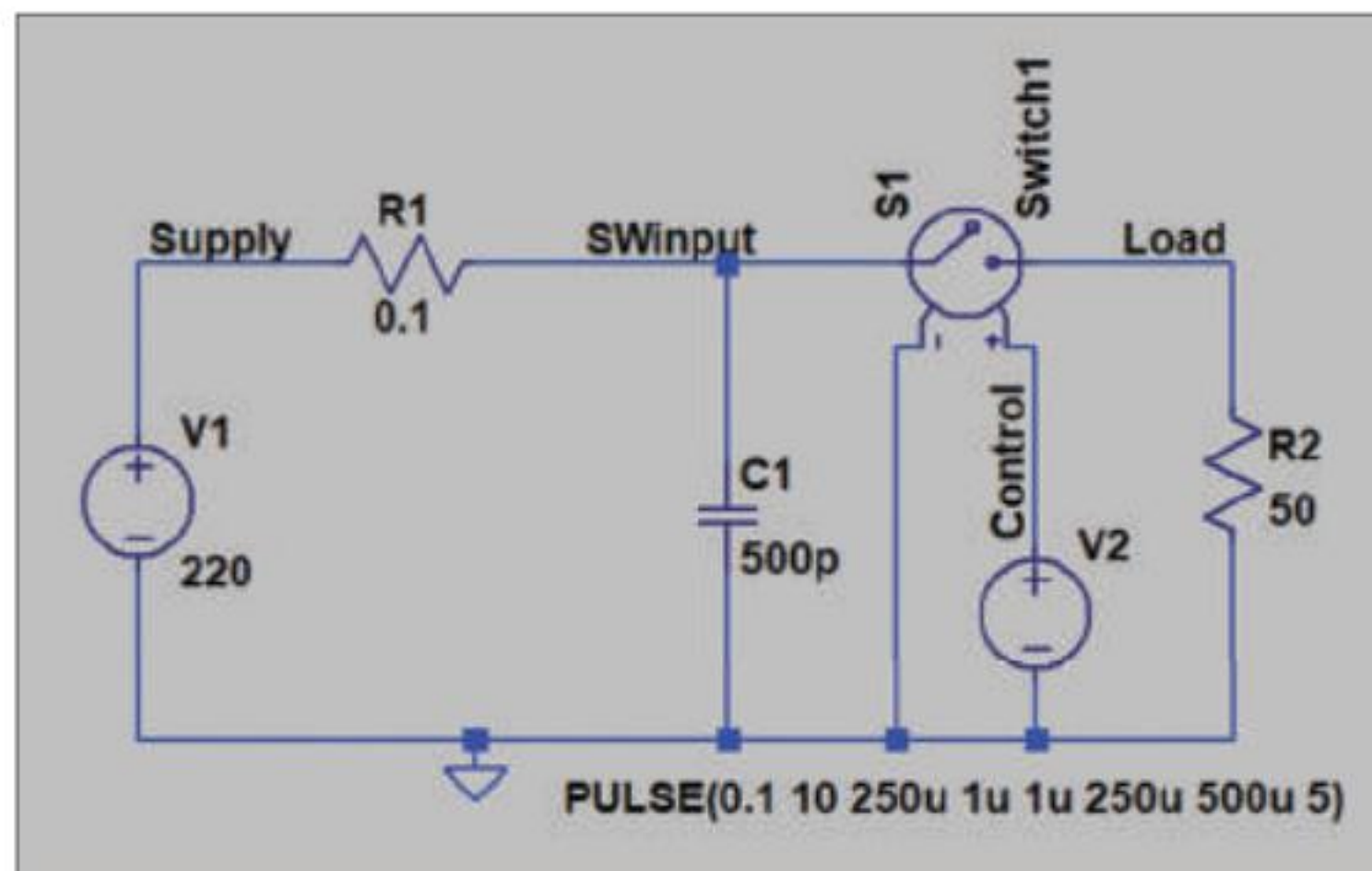


Fig.4. Schematic for simulation of the switching circuit without the non-functional Zener regulator.

well beyond the regulation limit of the Zener regulator in Fig.1.

Zener regulators were covered last month in Mike Tooley's *Teach-In* series and also Jake Rothmans's *Audio Out*, where their inefficiency was discussed. So we will not say too much more on the theory here, except to point out that at a current of 4.4A, a resistor dropping 110V (330V down to 220V) would dissipate a massive 484W – the Zener regulator is not a practical option here.

Ideal switch simulation

We can investigate the circuit in Fig.1 using an LTspice simulation. Sometimes, if a circuit is not behaving as expected it can be useful to simulate a more idealised version. This can help if the problem lies somewhere other than expected, or to untangle multiple issues. For example, in this case, someone focusing on understanding the MOSFET may miss the issue with the regulator. The schematic in Fig.2 is a version of Fig.1 for LTspice simulation in which the MOSFET has been replaced by a voltage controlled switch. This switch has a much simpler behaviour than a MOSFET; for example, its control input is completely independent of the voltage being switched and it can be activated at any control voltage we choose.

We can use a `.model` statement to set the switch's parameters, such as the on

and off resistances and the threshold voltage for the control input. The model used here sets the switch parameters to $R_{ON} = 0.01\Omega$, $R_{OFF} = 100M\Omega$, which is sufficiently close to ideal (zero and infinity respectively). The control threshold (for on/off) is a somewhat arbitrary 9V to match the original 10V control signal from V_2 (any threshold above 0V and below 10V would work). The switch's control input is driven with a square wave with a period of 500µs, as in Fig.1. The rise and fall times have been changed to 1µs because fast 1ns edges (Fig.1) are not needed here.

The simulation also needs a model for the 220V Zener. A number of real devices are available (eg, 1N4990) but for this simulation a shortcut was taken – the existing LTspice model for the 100V 1N5378B was tweaked to 220V by changing BV and IBV. As discussed above, the Zener regulator is not practical, so it was not worth setting up an accurate model for this illustration. The basics of Spice models, including Zeners, were covered in depth in a recent *Circuit Surgery* (January 2019) so we will not provide a more detailed explanation here.

The results from the simulation of the circuit in Fig.2 are shown in Fig.3. The voltage at the Zener ($V(Zener)$ – middle trace) is not a constant 220V, which it would be if the regulation was working. When the switch is off (control voltage at zero, see top trace) the voltage at the Zener rises relatively slowly to 220V due to C_1 charging through R_1 . When the switch closes, the regulator is unable to supply the current demanded to maintain 220V, so the load voltage, ($V(load)$ – bottom trace) goes to around 130mV, as predicted from our calculations above. The voltage at the Zener falls much more quickly than it rises because the load resistance (R_2) is much smaller than R_1 , discharging C_1 rapidly.

The circuit in Fig.4 removes the non-functional Zener regulator from the circuits in Fig.1 and Fig.2. This circuit is supplied directly from a 220V source with a small amount of internal or wiring resistance (0.1Ω), represented by R_1 . The switch model and simulation commands are the same as for Fig.2. The results

of simulating this circuit are shown in Fig.5. The load voltage now switches between 0V and 220V as required, and the voltage on the supply side of the switch ($V(swinput)$ – middle trace) is nearly constant at 220V. It actually varies a little due to the varying drop across R_1 as the load is switched on and off, but this is not visible in Fig.5.

MOSFET switch simulation

These simulations have shown that there is a problem with the circuit in Fig.1 not directly related to Michael's question on driving MOSFET switches. Now we have dealt with that, we can try the circuit with the MOSFET in place of the ideal switch. A simulation schematic for this is shown in Fig.6. This used the STP8NM60 MOSFET from STMicroelectronics instead of the SiHP8N50D because it was conveniently available in the LTspice library. We are aiming at a general illustration of circuit behaviour, not a detailed design, so this device is sufficiently close.

The results of simulating the circuit in Fig.6 are shown in Fig.7. The voltage across the load only goes to about 4.5V when the control signal is ON. Consider what happens when the control signal switches. Initially it is at 0V and the MOSFET is off. This means the MOSFET's source is also at 0V because no voltage is being dropped across R_2 . As the control voltage increases past the MOSFET's threshold voltage (set to 5.3V in the LTspice model) it will start to conduct. This will cause current to increase in R_2 , increasing the voltage at the source, but decreasing the gate-source voltage, which in turn will limit the current in R_2 . Once the control voltage reaches 10V a point of balance will occur such that the current in R_2 and hence the voltage across it, results in a gate-source voltage sufficient to maintain that current. The voltage across R_2 will be close to the control voltage (10V), minus the threshold voltage (5.3V), so around 4.7V. It is slightly less than this as the gate-source voltage has to be a little above threshold (around 5.5V) to produce the relevant drain-source current.

In the simulation we can provide a crude solution to this problem by setting the control voltage (V_2 source V_{on} PULSE parameter) to 230V (10V above the supply voltage) instead of 10V. This results in a load voltage waveform similar to that with the ideal switch in Fig.5. This gets us to the key point of Michael's question – how to implement the control circuit to provide the required voltage. We will look at this and other aspects of MOSFET switch circuits next month, but in the second half of this article we will introduce some MOSFET basics.

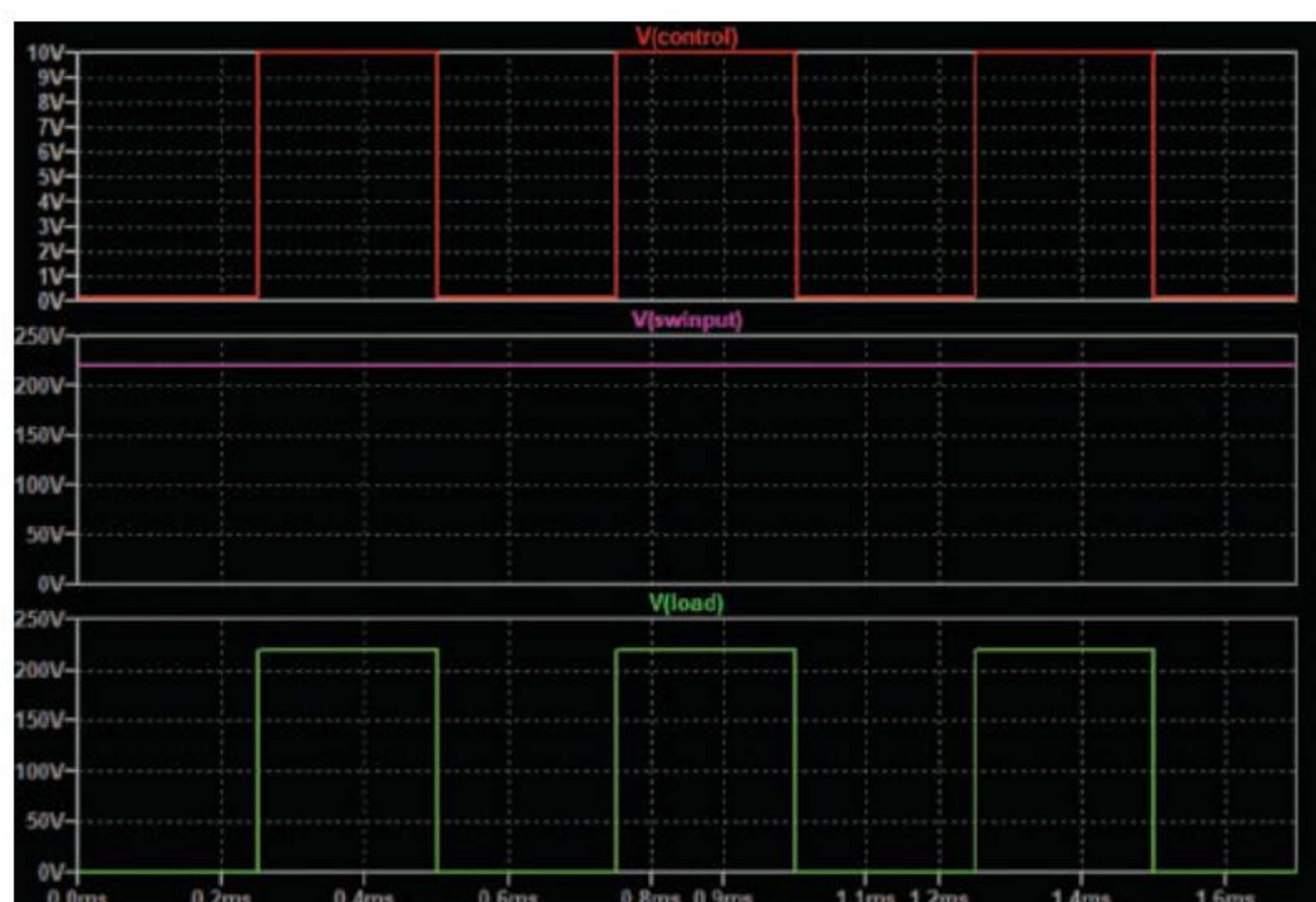


Fig.5. Simulation results from the circuit in Fig.4 – Top: $V(control)$; middle: $V(swinput)$; bottom: $V(load)$

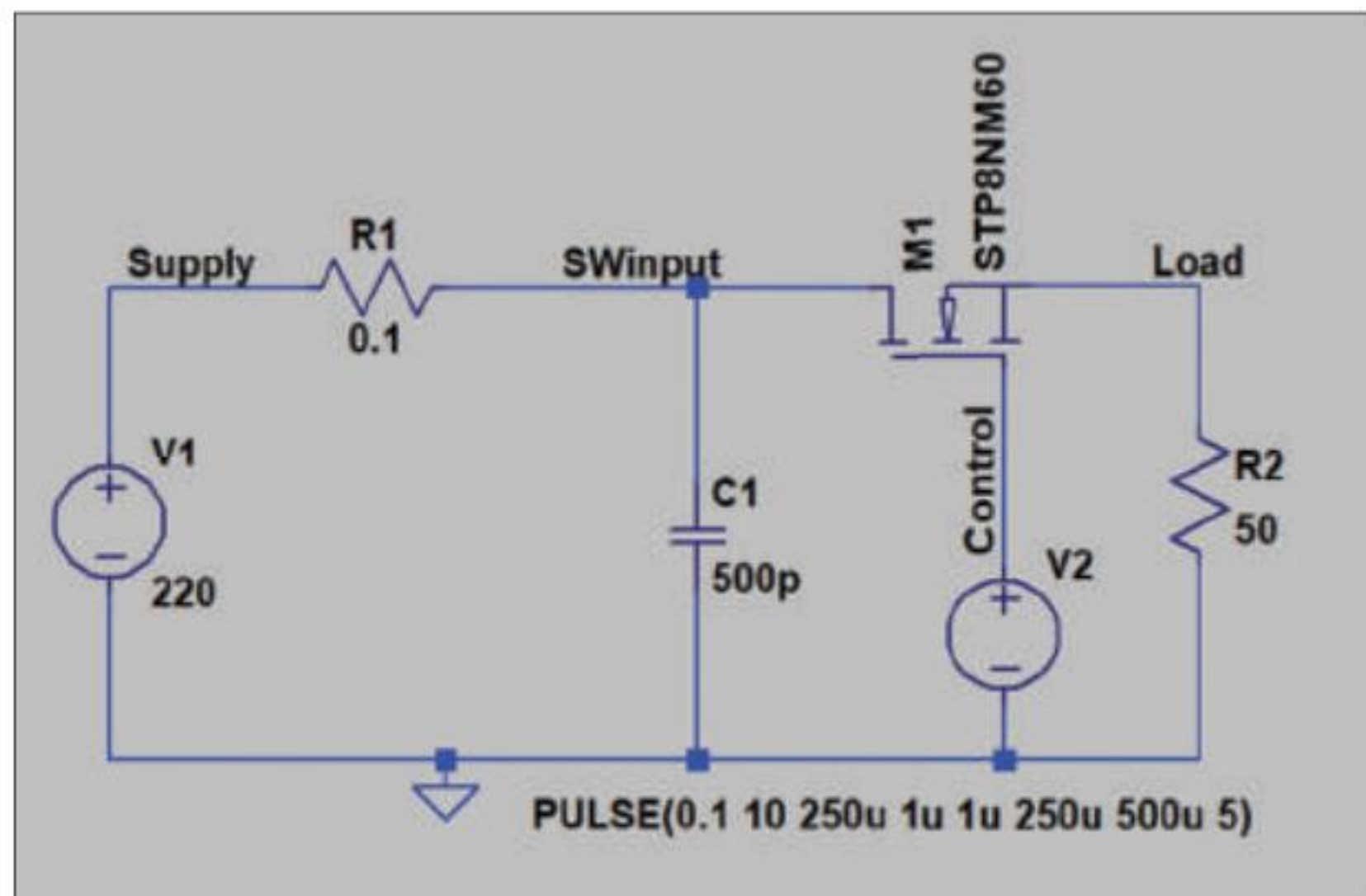


Fig.6. Schematic for simulation of the switching circuit from Fig.4 using a MOSFET instead of an ideal voltage-controlled switch.

MOSFET overview

The MOSFET is a semiconductor device which has three main connections – the gate (G), source (S) and drain (D). For those familiar with bipolar transistors, these correspond roughly with base, emitter and collector respectively. Like the two types of bipolar transistor (NPN and PNP) there are two types of MOSFET – N-channel and P-channel, often referred to as NMOS and PMOS transistors.

There are various forms of the schematic symbol used for MOSFETs – a version commonly used for power switching devices is shown in Fig.8. Strictly speaking, the MOSFET actually has four terminals – the fourth is the substrate or bulk (B) semiconductor in which the device is formed. In many cases (particularly discrete devices) the bulk and source are shorted within the fabricated structure of the device, so there are only three external connections. The bulk connection is represented by the line with the arrow in the centre of device, which links to the source. Fig.8 shows a power MOSFET symbol that includes the ‘body’ diode (on the right) which is an intrinsic part of the MOSFET’s structure. This diode

is not always included in the symbol, but is important in some power switching circuits.

MOSFET channel operation

The term ‘channel’ refers to the conducting channel between source and drain, which, as we will see, is a key feature of MOSFET operation. The ‘N’ and ‘P’ in NMOS and PMOS (and NPN and PNP) refer to the type of chemical additives used to ‘dope’ pure silicon to create interesting semiconductor behaviour. N-type silicon has more electrons free

to take place in electrical conduction than in pure silicon. P-type has fewer electrons than pure silicon, but these gaps can be regarded as mobile ‘holes’ that act as positive charge carriers, facilitating electrical conduction. Placing an N region next to a P region creates a PN junction, also known as a diode junction, through which current will usually flow in only one direction.

If a sufficient positive voltage is applied to a diode junction’s P side (called the anode) with respect to the N side (cathode) a current will flow. This is indicated by the arrow direction in the diode’s schematic symbol. Holes can flow from the P to N side and electrons from the N to P side. Electrons move in the opposite direction to that which we designate as current flow, despite the fact that most electrical circuits are connected using metal conductors, in which conduction takes place due to electron movement. This is known as ‘conventional current’. Historically, the convention of current being defined as flowing from positive to negative was agreed before the discovery of conduction by negatively charged electrons.

When a PN junction is formed, electrons from the N side move into the P side and holes from the P side move into the N side. They combine (effectively cancel one another out) to create a region close to the junction without any charge carriers. This is known as a ‘depletion region’. A diode conducts in forward bias when sufficient voltage has been applied to remove the depletion region. Reverse bias makes the depletion region larger, so no conduction occurs.

When a PN junction is formed, electrons from the N side move into the P side and holes from the P side move into the N side. They combine (effectively cancel one another out) to create a region close to the junction without any charge carriers. This is known as a ‘depletion region’. A diode conducts in forward bias when sufficient voltage has been applied to remove the depletion region. Reverse bias makes the depletion region larger, so no conduction occurs.

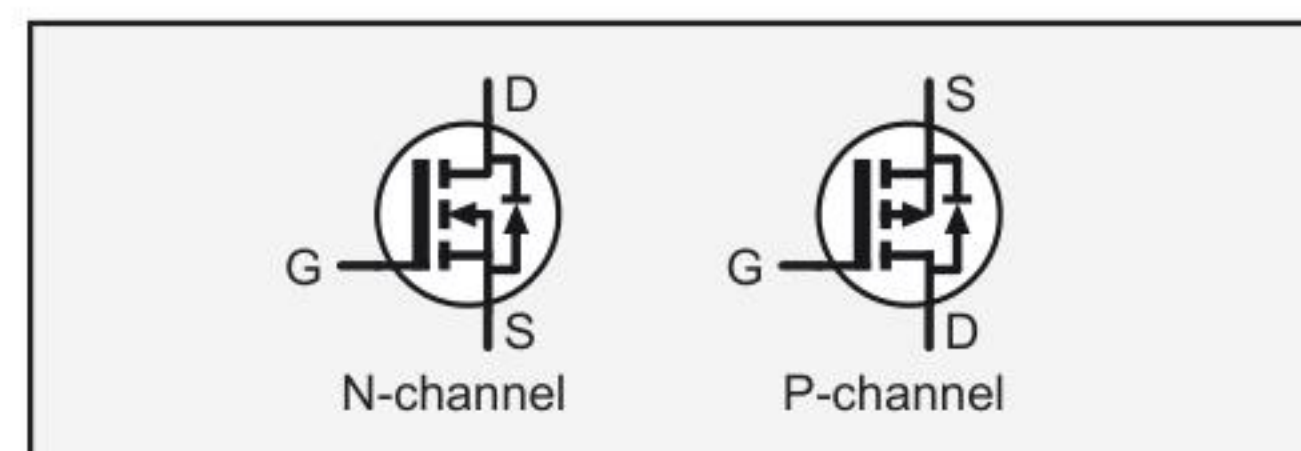


Fig.8. Power MOSFET symbols showing parasitic diode.

‘MOSFET’ is an acronym for ‘metal-oxide semiconductor field-effect transistor’. ‘MOS’ refers to the basic structure of the device, which comprises three layers: a conducting gate (metal), a thin insulating layer (oxide – specifically silicon dioxide) and a conducting channel (semiconductor). The voltage on the gate controls current flow through the channel, whose ends are connected to the device’s source and drain terminals. The gate insulation means that it is the electric field produced by the gate voltage, rather than gate current, which controls the channel current – hence the name ‘field-effect transistor’. Despite the name, the ‘metal’ layer does not have to be made of metal; it can also be a semiconductor, which is common for MOSFETs in integrated circuits.

Fig.9 shows a simplified cross section of an N-channel MOSFET with the four terminals: source, drain, gate and bulk. Many high power MOSFETs have different physical structures, but their basic principle of operation is the same and can be described using Fig.9. As can be seen, the structure is symmetrical, although it may not be in real devices. In the usual approach to general MOSFET theory, designation of which terminal is source and which is drain depends on the applied voltages (which means they can swap round in some circuits). For an N-channel device, current flows from drain to source, with the drain more positive than the source. Understanding that conduction actually occurs due to electrons moving from source to drain (opposite to conventional current) makes the terminal names make more sense. For a P-channel

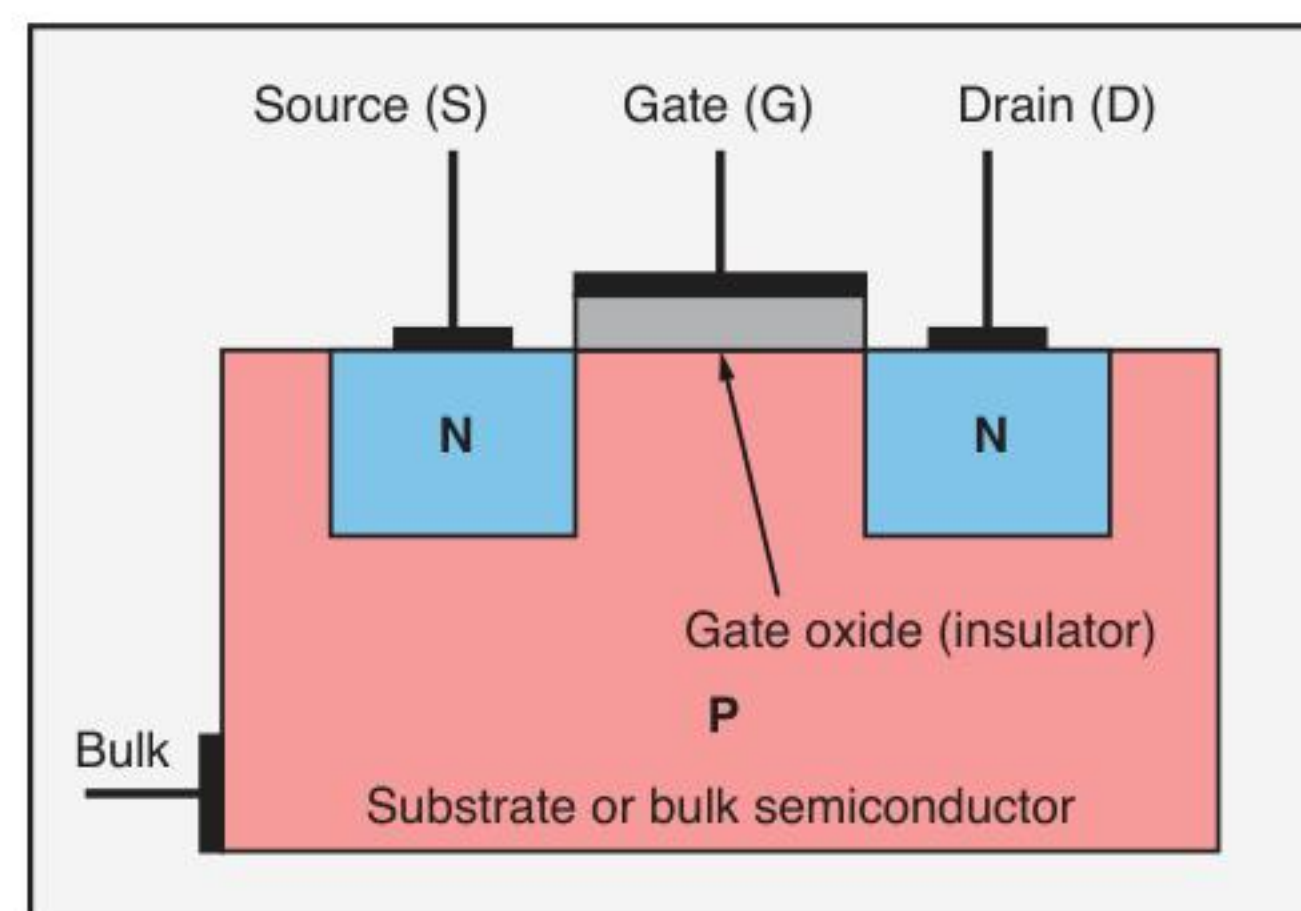


Fig.9. Cross-section of N-channel MOSFET with device off. The MOSFET acts as an off switch between source and drain. The voltage on the gate is small or negative with respect to the source and bulk. The drain-source voltage may be large.

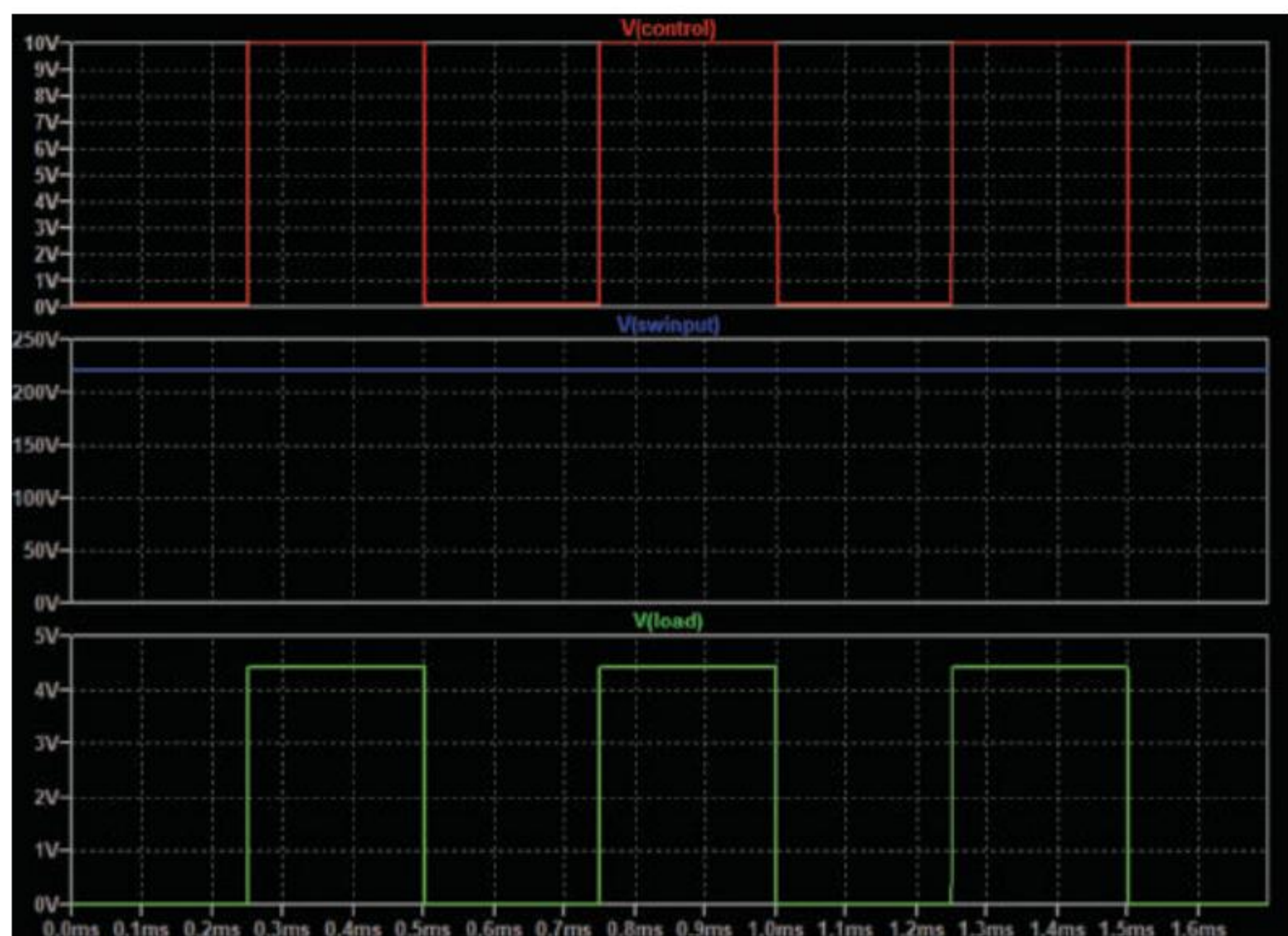


Fig.7. Simulation results from the circuit in Fig.6 – Top: V(control); middle: V(swininput); bottom: V(load).

device, conduction is by holes flowing from source to drain, so current is also from source to drain. The source is more positive than the drain for a P-channel MOSFET. In both cases the charge carriers flow from source to drain.

MOSFET gate capacitance

The basic MOS structure – gate/oxide/channel – is of the form conductor/insulator/conductor, so it resembles a capacitor. For this reason, the gate of a MOSFET behaves like and is treated as a capacitor. This is why the total gate charge (Q_g – when the device is on) is specified, as mentioned by Michael. Changing the gate voltage requires current flow to charge or discharge this capacitance, and the faster the device is switched the higher the gate current required. For large power MOSFETs the gate current can be very significant, hence the current capabilities of several amps for the MOSFET drivers mentioned by Michael. These high gate currents only flow temporarily while the gate voltage is changing.

Referring again to Fig.9, if we apply zero, low or negative gate-source voltage the device is off because the source-bulk and bulk-drain N-P and P-N regions act a bit like two back-to-back diodes, which together will not conduct in either direction. Thus, a conducting channel does not exist between source and drain and no current flow occurs if a voltage is applied across them. This situation is referred to as the ‘cut-off’ region of operation of a MOSFET. We can have a large voltage applied between drain and source but with no current flow between them, although in practice there will be some leakage current. The maximum possible drain-source voltage will depend on the point at which the device undergoes some form of electrical breakdown.

If we apply a positive gate-source voltage this will pull (negatively charged) electrons from the nearby silicon to the P-type region just under the gate.

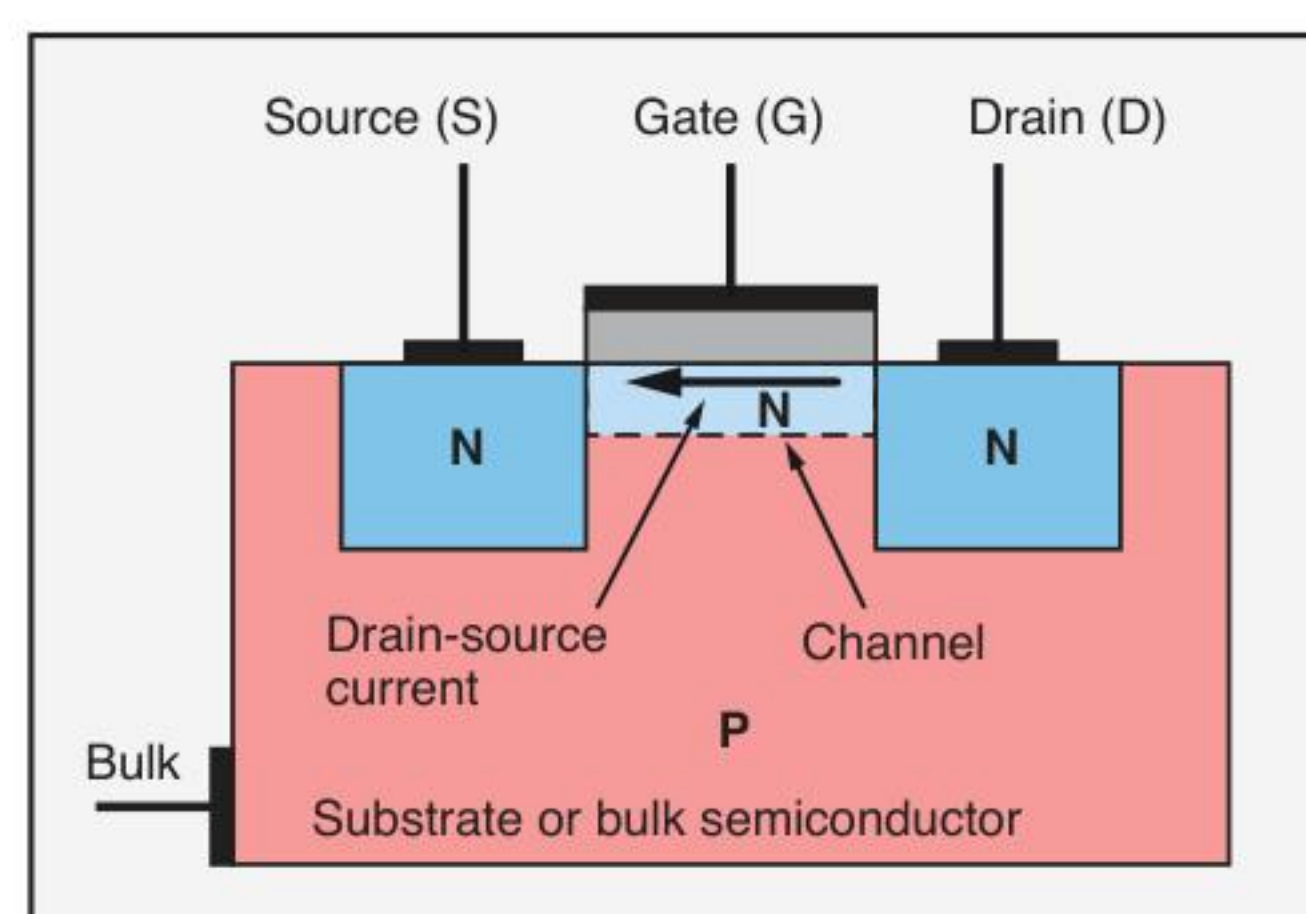


Fig.10. Cross-section of N-channel MOSFET with the device on. A positive voltage, greater than the threshold voltage, has been applied to the gate. The MOSFET acts as an on switch between source and drain. We assume the drain-source voltage is small.

If sufficient electrons accumulate here, there will eventually be an excess of electrons, so the area just under the gate will behave as if it is N-type silicon. At this point we will have created an N-type channel connecting the N-type drain and source regions, thus we have an N-N-N path from source to drain, rather than the N-P-N back-to-back diodes previously described (see Fig.10). Conduction can now take place from source to drain. The gate-source voltage at which the conducting channel just forms, and device switches on, is called the ‘threshold voltage’.

MOSFET gate drive

Power MOSFET threshold voltages are typically around 4V, but to fully turn on many of these devices for use at their full current rating, 10V or more may be needed. In some cases, a driver circuit will translate the voltage levels in the control circuit (eg, 3.3V logic) to those required by the gate (eg, 10V) as well providing the high current drive. Use of voltages well above threshold ensures saturated operation, in which the drain to source ON-resistance ($R_{DS(ON)}$) voltage drop across the device, and hence the power dissipation are all minimised. In switching applications the device should be either in the fully off state, where little or no power is dissipated, or the fully on state, where power dissipation depends on $R_{DS(ON)}$ and the drain-source current. Low $R_{DS(ON)}$ is therefore important in minimising power dissipation.

As previously discussed the MOSFET’s gate has significant capacitance. In order for power MOSFETs to switch quickly and efficiently, sufficient current must be available to quickly charge or discharge the gate capacitance of the device. The driver circuit’s source resistance and the resistance of the wiring both inside and outside the device cause the gate voltage to follow an RC charging curve, so the MOSFET will spend some time in-between being fully on and fully off. During this time the device may dissipate a lot of power, a problem referred to as ‘switching losses’. The drive circuit therefore must be able to supply enough transient current to charge the gate capacitance at the required rate. In some cases this current may be quite substantial, particularly for large, very high-power devices, or where paralleled MOSFETs are being used.

Further design issues

The effective capacitive of the MOSFET gate and hence the drive current required is increased by the Miller effect. The Miller effect occurs when a capacitor is connected to produce negative feedback in an amplifier – the gate-drain capacitance in this case. The capacitance is

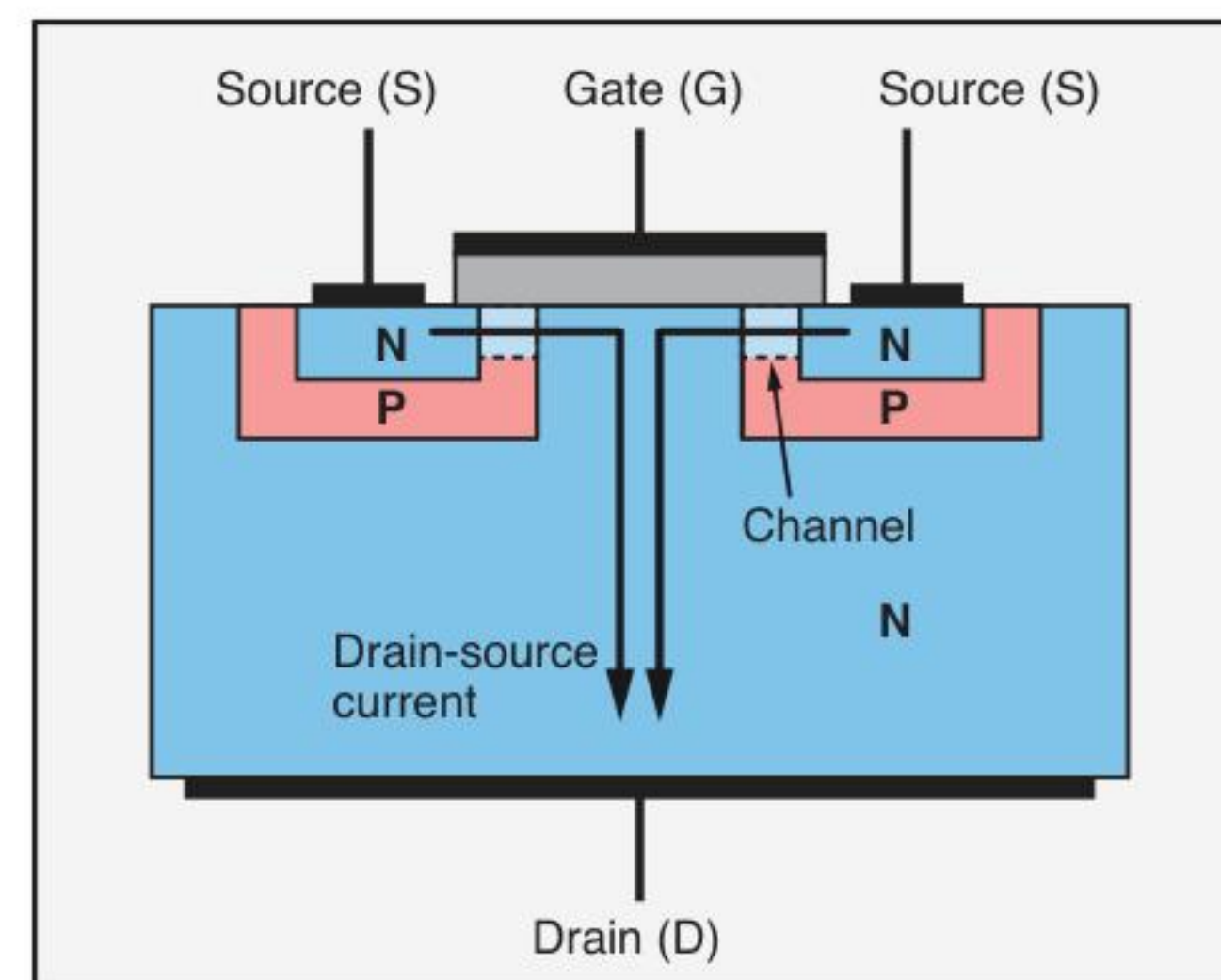


Fig.11. Simplified planar-style power MOSFET Structure, showing current flow.

multiplied by a factor related to the amplifier gain to create an *effective* capacitance. The dynamic capacitance of power MOSFET gates during switching is complex and can be difficult to analyse. Basically, this means that driving the gate is probably harder than it first looks, hence the need for good driver circuits.

The physical structure of the MOSFET device shown in Fig.9 is not easily amenable to producing high-power devices – it is difficult to make the cross-sectional area of the conducting region big enough. If this area is too small the transistor’s resistance will be too high, resulting in excessive power dissipation when it is conducting large currents. The basic solution is to use vertical current flow. The devices can have either flat (planar) gates, as shown in Fig.11, or use a groove or trench structures, as shown in Fig.12. Terms such as ‘trench’ and ‘deep gate’ occur in MOSFET product names to reflect the shape of these structures.

Discrete MOSFETs can be connected in parallel to provide higher current-handling capability (effectively reducing $R_{DS(ON)}$). Unlike with bipolar transistors, parallel MOSFETs do not always suffer from destructive current hogging and thermal runaway. As well as being useful in circuit design, the paralleling of MOSFETs is exploited by device manufactures to enhance device performance. Power MOSFET structures effectively containing many transistors are created in parallel to give high current capability.

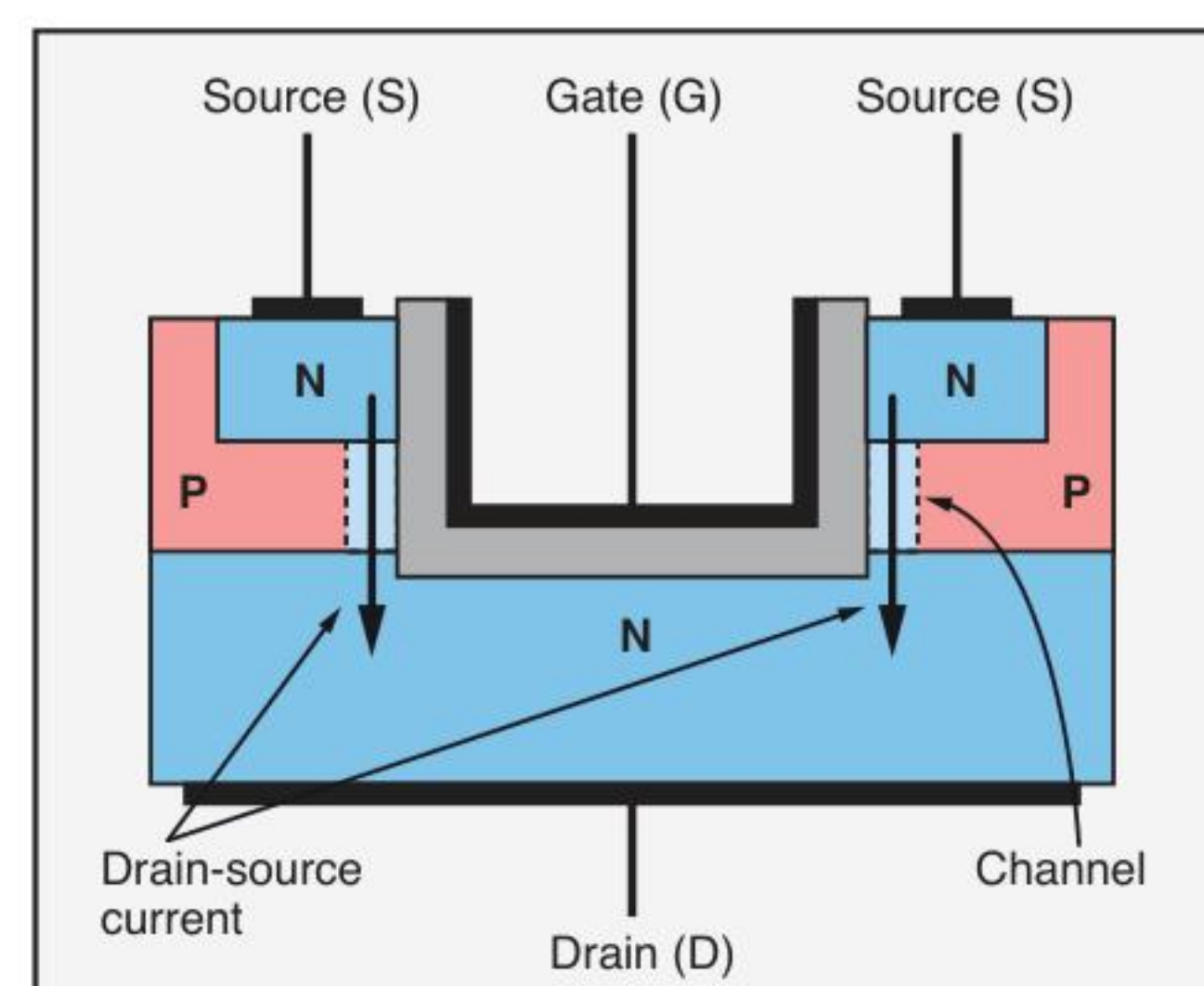


Fig.12. Simplified trench-style power MOSFET structure, showing vertical current flow.

PICn'Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Building circuits with SMDs – Part 2

Following on from February's article, we'll continue this month with a description of the creation of a professional PCB for last year's *Audio Spectrum Analyser* article series, a project that was built on breadboard. Here, is an overview of the approach we took for the design of the PCB, and how the PCB's surface-mount components are assembled, and the performance of the resulting circuit. This article is not a typical construction project – although it may become one later in the year – but

a demonstration of the application of professional PCB manufacturing services to hobbyist projects. It also serves as a 'taster' for the EagleCAD article that will follow next month.

The schematic for this design, updated from last year's article, is shown in Fig.1.

When designing a PCB for a 'product', be that a commercial solution or a one-off home project, you have to think about the intended enclosure before committing to a PCB outline. There are

two key points to consider: How will this device be powered, and what enclosure will we place it in? Sometimes, it is worth spending a little more money to make a larger PCB just so it will fit in an off-the-shelf enclosure. This is a perfectly fine approach; PCBs are cheap. If you are trying to make a professional device that is as small as possible, minimising the PCB dimensions and creating a custom enclosure are a better approach. Professional custom enclosures cost tens of thousands of pounds,

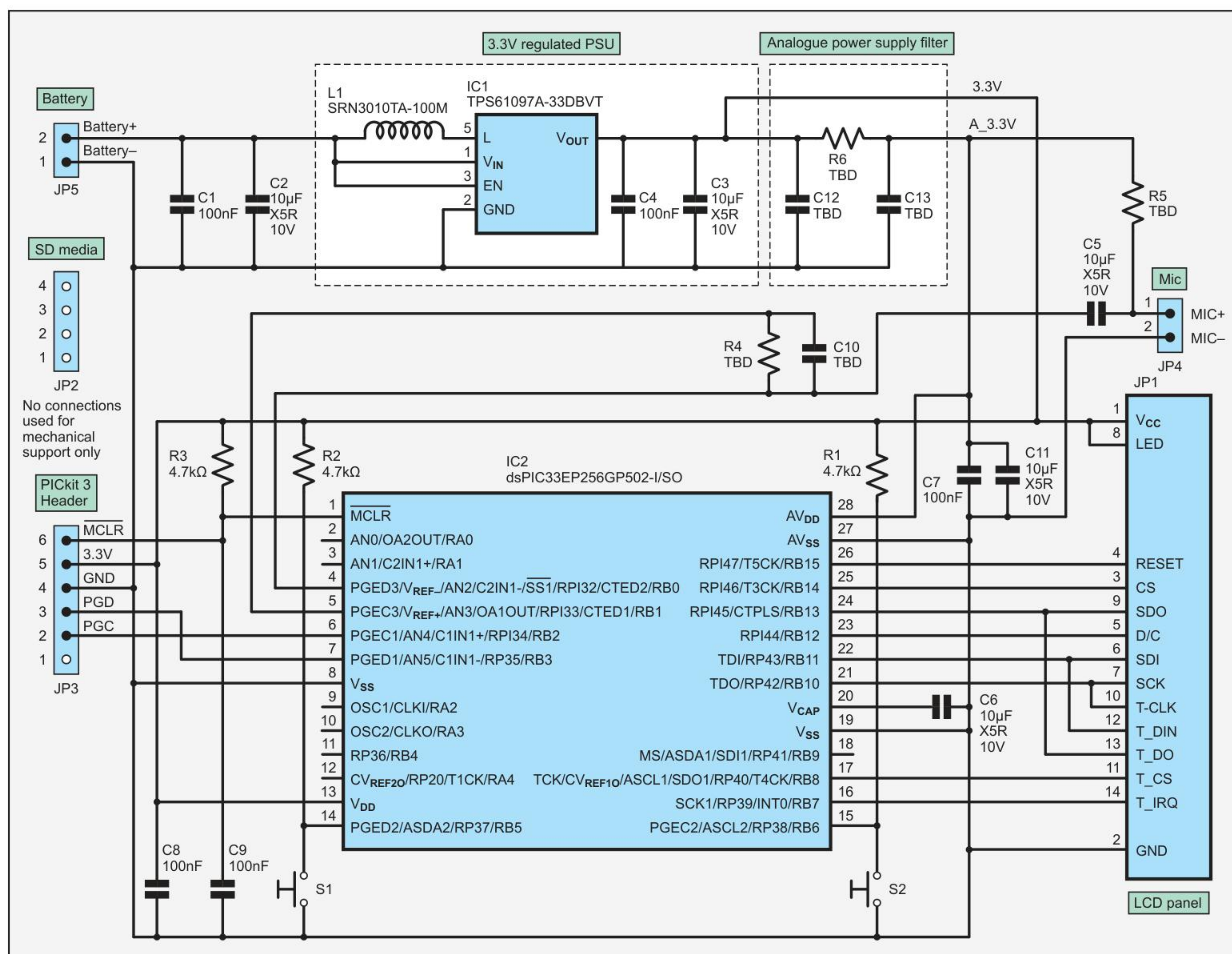


Fig.1. Revised schematic of the *Audio Spectrum Analyser*. This is the circuit we are constructing in this article (note: filter not yet designed).

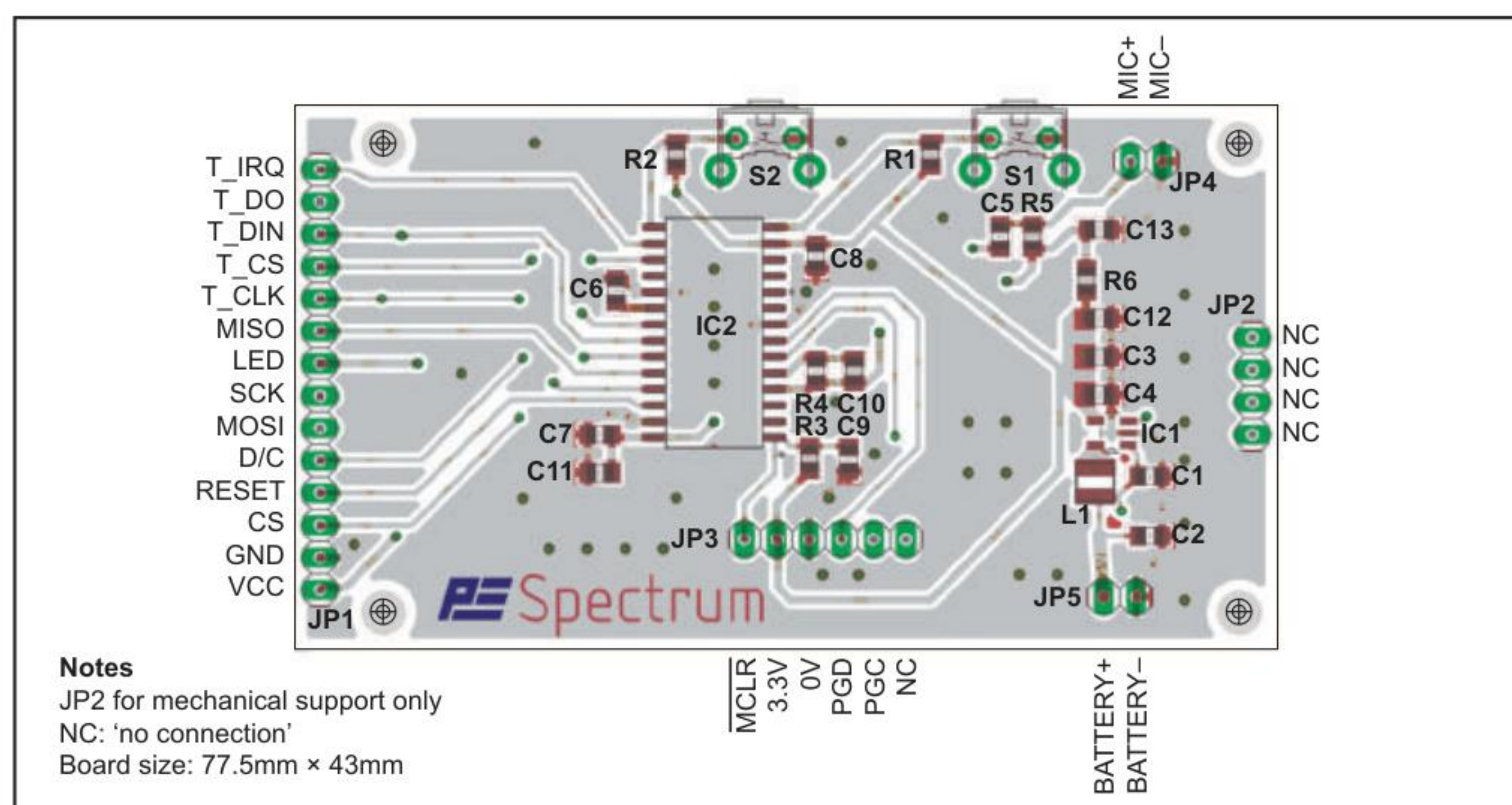


Fig.2. Audio Spectrum Analyser PCB design, produced in EagleCAD.

but for us hobbyists, a 3D-printed enclosure could be perfectly acceptable. We discussed 3D printer kits for home use nearly a decade ago (*EPE*, December 2009 – February 2010), but it is only now that entertaining the idea of owning your own 3D printer is really becoming a reality.

Although costs have come down to a fifth of the 2010 prices, hobbyist 3D printers are still temperamental machines that demand skill, care and patience. The author's own 3D printer is more often broken than working! Despite these challenges, chances are you either own a 3D printer or know someone who has one, so it's worth considering, and we will try to design an enclosure in a later article. The PCB, however, has been designed so that it is easy enough to mount in an off-the-shelf enclosure if you prefer, with a fair amount of modification to the enclosure.

PCB design

The idea is to create a PCB with the same dimensions as the LCD panel, with the same holes, so we can mount our board on the back of the LCD. The header pins on the LCD panel will solder directly to our board, removing all those connecting wires. The first question we are presented with is where will we place our components? On the top or bottom of the board?

The SD Media card slot takes up a lot of space on the LCD panel, so we will put the components on the side of the board facing away from the LCD. We will have to provide a spacer between the two boards, not only for mechanical stability, but also because the SD Media card on the rear of the LCD is slightly taller than the connector insulation stand-off height. 5mm spacers are available from Farnell, part code 1733418, costing 12 pence each. An M3 locking nut works just as well, however. In the end, we did not bother – we found the

header solder joints provided enough mechanical strength. We still carefully spaced the boards at 5mm separation prior to soldering the headers in place.

We have chosen to mount the switches on the top edge of our board so they can be accessed through any enclosure from the top of the device.

The microphone will connect to a two-pin header so it can be mounted off the board, if that suits you better. Other microphones of a similar type should work fine, and in theory it should be possible to route an external audio source in, provided it is attenuated to a few millivolts. Be careful to wire any electret microphone correctly, as this type of microphone has a built-in amplifier, and so has polarity sensitive pins.

We selected through-hole-mounted push switches and located them to the left of centre of the board to avoid anything on the LCD PCB from interfering with the switches' 2mm protruding lugs.

The final PCB design within the EagleCAD program is shown in Fig.2.

Components

Purchasing surface-mount components is an experience similar to purchasing leaded components – but with some exceptions. First, you often have to buy them in multiples of five or ten parts. For components costing a few pennies each, this is no big issue – the rest will go in your component stock. It's always a good idea to buy a few extras of the smaller components anyway because they are so easy to lose if you drop them. Second, the smaller components are typically supplied in a tape with sprocket holes on one edge, as shown in Fig.3.

These strips are cut from a longer strip, often manufactured on reels, which are used on automated assembly machines. Each component is sealed in a small cavity by the adhesive tape; to gain access to the component simply peel back the tape with tweezers or finger nails. Only expose the number of components you intend to use, as the tape provides a degree of protection from moisture in the atmosphere.

If you decide to keep your components in the bags that they were supplied in, take care to write the values on the original label. The inks used by component distributors fade quickly, and we have thrown out many a bag of potentially useful components which are un-identifiable. This appears to be a recent 'innovation' from suppliers, possibly to encourage the purchase of newer parts! For prototype builds of circuits by hand, however, we have never had a problem with components that are years old, if they have been kept in a dry environment.

Ordering PCBs

We chose the Chinese company PCBWAY.COM based in Shenzhen to manufacture our boards. We were able to order ten of these boards on a two-day turn-around for just £4.50. Forty-day shipping costs an extra £6, but we went with DHL express for £18 and the boards were with us in five days. All communication with the company is through the website, and unless there is a problem with your PCB design files, requires no communication with a real person. All aspects of their business operate 24 hours a day, so service is immediate. You can see the boards, with the LCD module, in Fig.4.

No matter how many boards you order, do order enough so that you have at least one spare that you do not place components on. This can serve as a reference when checking a board for shorted tracks, potential manufacturing errors or for taking measurements when fitting into an enclosure. This information is available electronically in your CAD program, but nothing



Fig.3. SMD components for the Audio Spectrum Analyser.

beats having a physical board in your hand when you need it.

Assembly

With any new PCB design it's wise to assemble the circuit 'building block by building block', testing at each stage. We typically start with the power supply, then add the fewest components required to get the microcontroller operational. For novices with limited SMD soldering skills, it's also important to solder the most difficult devices first – so if you mess up your board, fewer components get wasted. By coincidence the most difficult device to solder is also the power supply IC, so the sequence for construction is clear:

- Solder the DC/DC converter components: IC1, L1, C1, C2, C3, C4
- Power the PCB and make sure you are getting a regulated 3.3V supply with 1.5V input. The current consumption should be very low, below 1mA
- Solder the minimal microcontroller circuit: IC2, C6, C8, C9, R3

With this particular design and choice of components, only the microphone, IC1 and IC2 are polarity sensitive; all other components may be soldered in any orientation. It's safe to power a board with an un-programmed microcontroller, and this should be done and the current consumption measured as another check that there are no solder shorts or component placement errors. Then, re-check that the supply rail is still showing 3.3V.

Unusually high currents measured at this point typically indicate a shorted track, an IC placed in the wrong orientation or resistors used in place of capacitors by accident. The next most common issue is the firmware incorrectly driving a pin as an output when it should be an input. An un-programmed device has all pins set as inputs, so an unwanted output should be easy to spot (especially if you have an oscilloscope; two output signals driving the same wire will often result in a 'mid-rail' voltage level. Or smoke, if you are unlucky.)

PCB solder pads look solidly attached to the board and well stuck down, but once heat is applied, they lose their

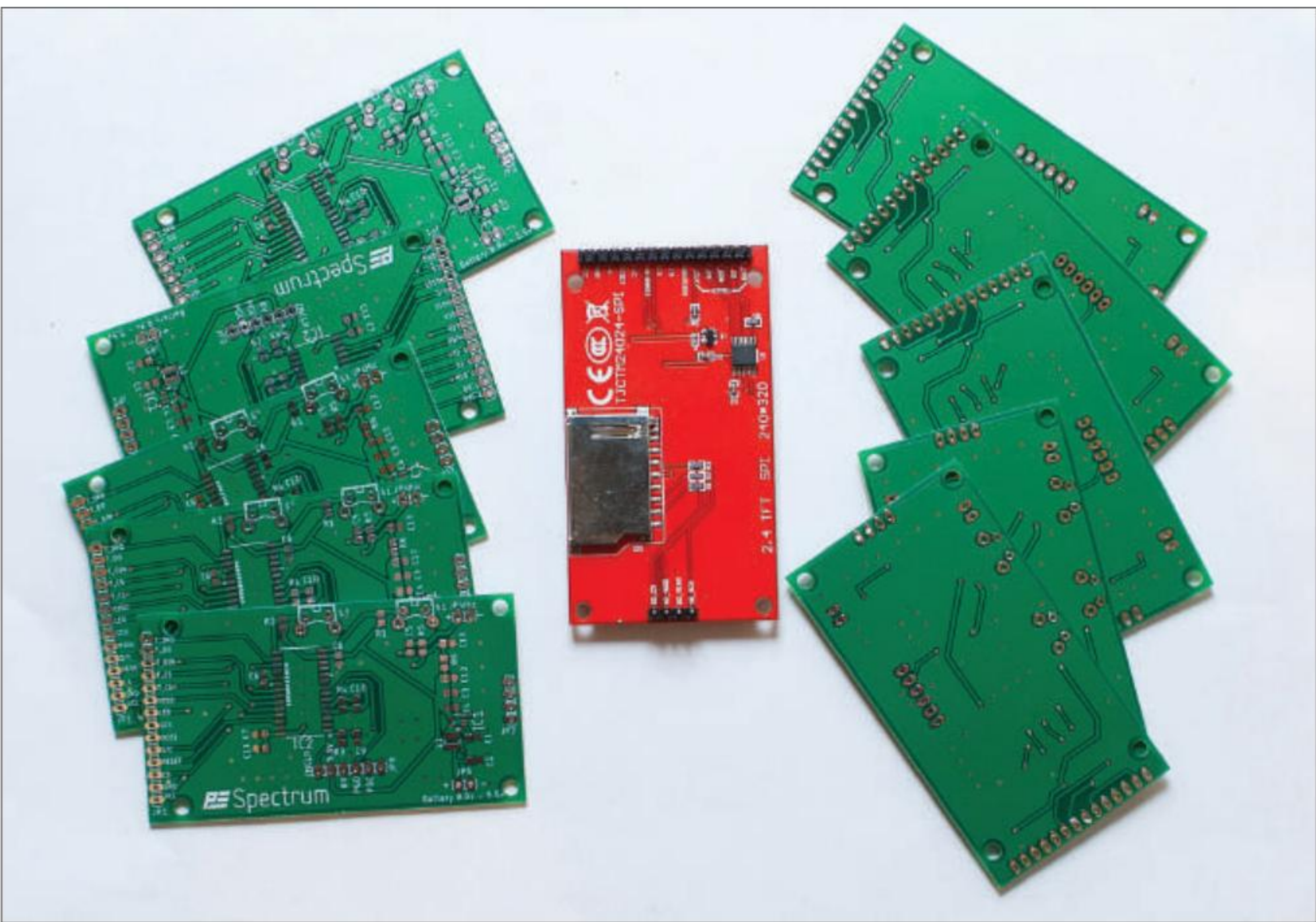


Fig.4. The delivered *Audio Spectrum Analyser* boards (plus touchscreen in the centre).

adhesion to the FR4 laminate – so be careful not to overheat the pad and then push or pull on the pad at the same time; it will break off.

For those who are interested, the component list is as follows:

Qty	Part	Farnell Part#
1	Mic	2066499
1	Inductor	2808292
2	Switch	2452343
1	header strip	2356175
1	Regulator	2492461
7	10µF cap	1759476
8	100nF	2495190
4	4.7kΩ	9334580
1	DSPIC33	2212178

Soldering SMDs

The technique for soldering a surface-mount component, be it a 2-pin resistor or a 28-pin IC, is the same. Apply a small drop of solder to one corner pad, then optionally cover the remaining pads in liquid flux (It's hard to see in Fig.5a, but it's there. It leaves a thin sticky film.

Using tweezers, position the component over the pad and apply heat to the pin, melting the solder underneath, while trying to line the chip up correctly. Next, put your tools down and look at the positioning of all pins. In

the middle image of Fig.5 you can see it's not quite right. So, heat the joint up again and reposition it.

Once happy with the position of the device we can apply solder to all the other pins, opposite corner first, and finally re-touch the first pin soldered – it's probably not perfectly soldered, as the component would have moved slightly as the solder cooled. Fig.5 shows an example of poor (b) and good positioning (c).

The next step is to add all the remaining components for the power supply section: L1, C1, C2, C3 and C4. Again, even with these simple two terminal devices, first solder a single pad, affix the component, check its orientation, solder the second pad when certain it is aligned correctly, then touch up (if necessary) the first pad. It's a slow process, but faster than working with leaded components as there are no wires to trim back after soldering each component.

After a quick power-up to confirm that the power supply is providing 3.3V, add a ¼W 33Ω resistor to the 3.3V output to check regulation under different input voltages. For this 100mA load, regulation on my circuit held up until the input voltage dropped below 1.4V, confirming that the boost regulator was working. If the current consumed with

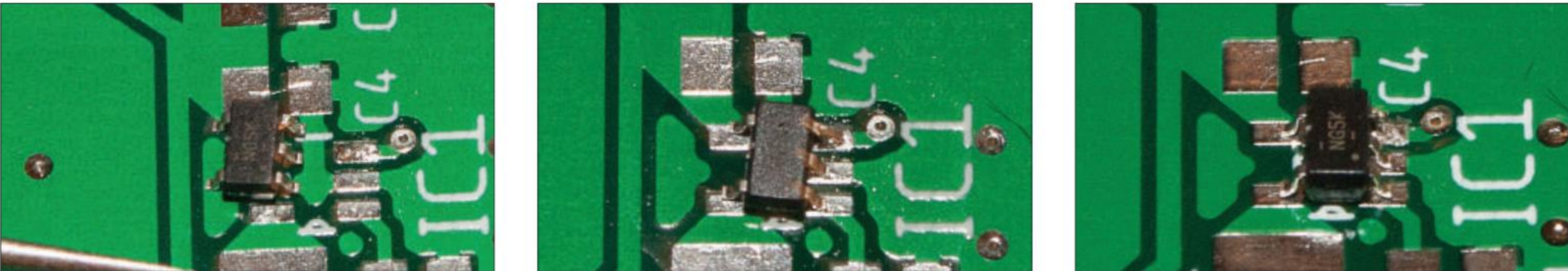


Fig.5. (L-R) i) Apply a small drop of solder; ii) Soldering a single pad (top right) – the chip is not well aligned; iii) Now nicely positioned



Fig.6. The completed project comes to life! no load applied (the quiescent current of the power supply) is around 8µA, then the circuit is fine.

As we do not yet know whether we will need any additional power supply filtering (components C12, R6 and C13) bypass the filter by simply shorting the R6 pads with a solder bridge.

Next up, we installed the minimum components required to get a functioning and programmable microcontroller circuit present. This meant components IC2, C6, C8, C9 and R3, plus the 6-pin header required for connecting the PICKit 33 programmer. Once again, a quick measurement of the current drawn by the circuit with the un-programmed PIC circuit fitted was performed to check things were OK, and there were no shorts. My circuit indicated 6mA, which seemed reasonable. Finally, we needed to check if the circuit could communicate with the processor via the PICKit 3.

We fired up MPLAB X IDE with the project code from last year's article and loaded the original article code (Note that we changed the processor type from the 512K variant to 256K – the 512K variant is no longer available from Farnell, so we switched to the cheaper, slightly smaller memory variant.) The code loaded to the device with no complaints.

Next, we progressed to wiring up the remaining components – leaving C10, C12, C13, R4 and R5 unpopulated, and placing C13, R4 and R5 (TBD) initially with the values used in the original design, just to verify the original functionality. You can imagine our delight when the device burst into life, as seen in Fig.6.

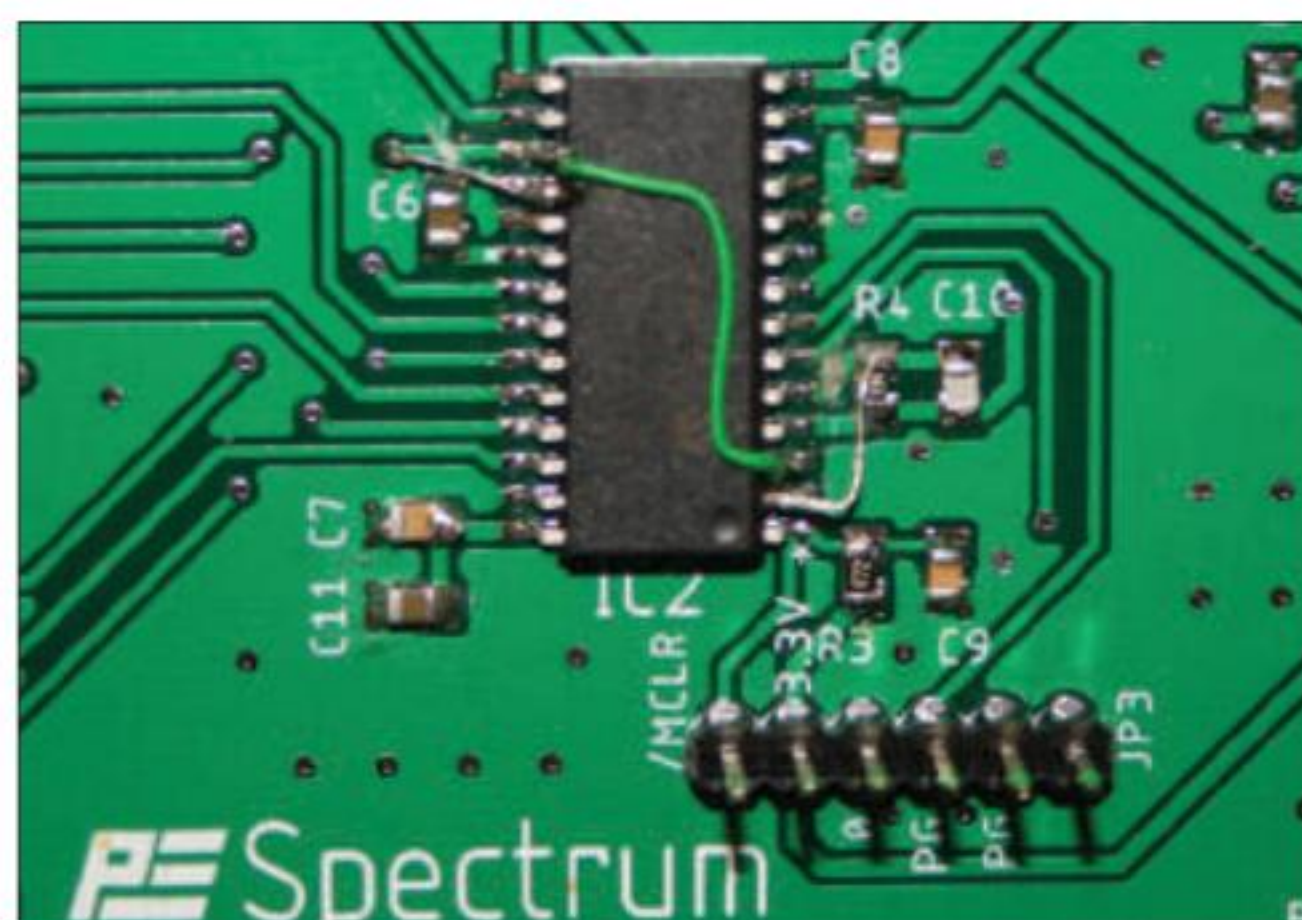


Fig.7. Close-up of soldered components, plus PCB-error-correcting modifications.

That delight was quickly tempered when we discovered the first issue with the PCB itself – a key link on the PCB was missing, one that routes the processor's ADC reference voltage output back into the same chip on another pin (pin 17 to pin 3). Pin 17 is used to connect to the touch screen controller in this design, so that pin's signal needs to move up one to another (thankfully!) free pin. You can see the resulting modifications in Fig.7. The second iteration of the PCB will remove those wires, and any other issues we find.

This kind of modification is typical in the electronics industry, and it is not uncommon to find 'bodes' like these actually make it into production devices. Sometimes the cost of modifying a PCB design and re-manufacturing devices, with existing products being scrapped, can exceed the additional cost of cutting a track and soldering two wires. Held in place by a small amount of glue, these modifications can be just as reliable as the intended design. Sometimes, these wire links are added during the design, to avoid requiring more complex PCBs. In our case, it was just an error in transferring the original schematic to the EagleCAD program.

For now, until we find any other issues with the design, we'll leave the wire link as is and use this board rather than scrap it.

Next steps

In a later article we'll look at the code and component value changes required to make this design work across the entire audio range and add some functionality to the touch screen and buttons. We'll also look at designing a 3D printable enclosure for it, as access to 3D printing technology has become very affordable in recent years. Studying the power supply signals with an oscilloscope we did notice considerable noise present, coming from the DC-DC converter. So that power supply filter circuit will need to be looked at.

Through the magazine website we are making the (corrected) EagleCAD design files available, including the 'template' board design files, so you can make your own designs that mate to the LCD panel. If you do design something new, please let us know.

Next month

Next month, we will return to the process of designing boards with EagleCAD, and how to engage with PCB suppliers to have your own boards professionally manufactured.

PoLabs

For more information or software download please visit 

www.poscope.com/epe

PoKeys Connect, Control



- USB
- Ethernet
- Web server
- Modbus
- CNC (Mach3/4)
- IO
- PWM
- Encoders
- LCD
- Analog inputs
- Compact PLC

Stepper motor drivers Drive



- up to 256 microsteps
- 50 V / 6 A
- USB configuration
- Isolated
- up to 32 microsteps
- 30 V / 2.5 A

PoScope Mega1+ PoScope Mega50 Measure



- up to 50MS/s
- resolution up to 12bit
- Lowest power consumption
- Smallest and lightest
- 7 in 1: Oscilloscope, FFT, X/Y, Recorder, Logic Analyzer, Protocol decoder, Signal generator

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 2 – Building the Micromite Keyring Computer

In last month's column we gave an overview of what this exciting new series will be covering. For those of you that missed *Part 1*, over the coming months we will be showing you just how easy it is to learn and use the extremely powerful Micromite. We will work through numerous simple examples covering a wide range of topics, and along the way we will build several customisable mini-projects that demonstrate how you can quickly create some very impressive gadgets. Most important of all, we want to open up your creativity by empowering you with knowledge, allowing you to easily design and build your own Micromite-based projects incorporating features way beyond what you ever believed possible.

The good news is that you will not need to wait for the end of this series to begin having fun. Each month, we will demonstrate useful techniques that you can immediately use in your own projects. You will also be able to follow our new blog (micromite.org/blog) where we will be posting more information about the

topics covered. You will also have the option to give us your feedback, along with any ideas and comments – something we value very much indeed.

We hope you will join us on this journey, and discover why our motto is: *Simple – Interactive – Fun*

Before we start learning about the powerful features of the MMBASIC language on which the Micromite is based, we will begin this month by showing you how to build your very own *Micromite Keyring Computer* (and next month, the accompanying *Development Module*). These two low-cost 'self-build' projects will not only be used throughout this series, but also will prove to be extremely useful tools for all your future Micromite project developments. So let's get started!

MKC circuit description

The circuit diagram for the *Micromite Keyring Computer (MKC)* is shown in Fig.1. As you can see, it is very simple, comprising a power supply, the 28-pin Micromite DIP chip, three rows of sockets, and just a small number of passive components.

Power for the *MKC* is derived from an external 5V power source, which is connected to a micro-USB Break-out Board (BoB). This conveniently supplies the required 5V supply from the surface-mount micro-USB connector to a 0.1-inch header (J1). The 5V and 0V connections feed into the voltage regulator (IC1) which in turn provides the 3.3V output required by the Micromite (IC2). Two 10µF tantalum capacitors (C1 and C2) provide the necessary input and output voltage smoothing.

The Power LED (D1) is fed from the voltage regulator's 5V 'input' rather than its 3.3V 'output'. This allows you to use any colour LED (blue and white LEDs generally require more than 3.3V to operate). Current-limiting resistor R1 is required to protect the LED, and its value can be changed to give an appropriate level of brightness for the LED used. Typically, a value between 330Ω and 4.7kΩ should be suitable; the higher the value, the dimmer the LED.

The 10µF tantalum capacitor (C4) connected to pin 20 on the Micromite is used to decouple and stabilise the 1.8V voltage regulator internal to the PIC32 chip. It is an essential component and cannot be omitted; furthermore, C4 must *not* be an electrolytic. (A multi-layer ceramic is an acceptable alternative to tantalum, as long as its value is between 10µF and 47µF).

R2 and C3 are not essential; however, they do provide a clean reference voltage when measuring analogue inputs, so they are included in our design.

Finally, the three female sockets (J2, J3 and J4) provide the ability to connect and use external hardware. Connections that are made available to the outside world include:

- All 19 Micromite input/output pins
- 0V, 3.3V, and 5V power outputs
- The Micromite Console pins (serial TxO and RxI); used to connect a computer, allowing programming, debugging and configuring of the Micromite

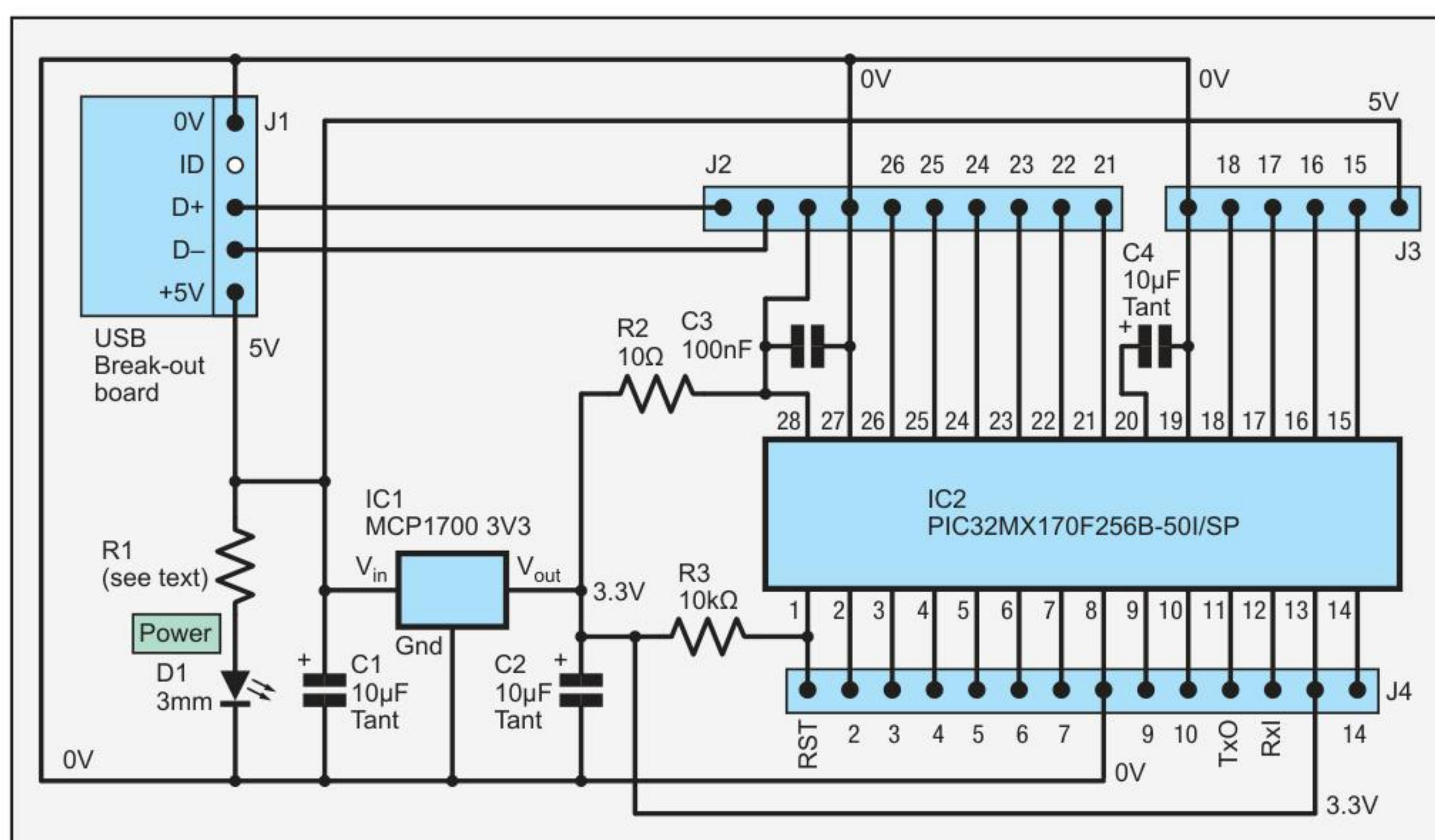


Fig.1. Circuit diagram for the *Micromite Keyring Computer (MKC)*.

- Two signals from the USB BoB (D+ and D-) that are used by the *Development Module* to allow firmware updates (more details next month).

MKC construction

You do not need to be an expert to construct these two projects. In fact, they have been designed with easy assembly in mind, even if you are a beginner. Although they contain a small number of components, you will end up with a very powerful and useful product. However, for it to work correctly, you will need to be able to solder through-hole components and wires to stripboard. If you are not confident with this, then we would recommend that you first practice by soldering some spare through-hole components (resistors and wire) to a piece of scrap stripboard.

The construction details described here assume that you will be building the *MKC* as shown in the photos; and that you will mount it into the recommended keyring-sized case. However, if you prefer to tailor things to meet your own requirements (for example, you may wish to have multiple rows of pin connectors instead of sockets, and have them laid out differently) then feel free to use these construction details as a helpful guide. At the end of construction, you will still have a Micromite computer capable of doing all the things that we will be covering throughout this series.

You can source your own parts or you can purchase a complete kit, including the case, from micromite.org

In addition to the components listed last month (as shown in Fig.1) you will also need some basic tools to complete the assembly:

- Soldering iron – a small ‘chisel tip’ is recommended (or a ‘pointed tip’ if you prefer)
- Solder – use a fine grade to minimise too much solder from accidentally creating shorts between tracks (0.5-0.7mm is ideal)
- File to help size and shape the stripboard
- Pair of small, sharp side cutters to cut the stripboard and for general assembly
- Small (3-5mm) metal drill bit to help cut the stripboard tracks (dedicated track-cutting tools are also available – for example, eBay item 290941443967)
- Small cross-head screwdriver to assemble the recommended case.

You may also find the following optional items useful:

- Needle-nose pliers to neatly bend component leads and accurately prepare wire links. If you don’t have any, then don’t worry – you can bend component leads and wire links, with your fingers
- Small flat screwdriver, useful to help ensure there are no shorts between strips

- Multimeter with ‘Resistance’ and/or ‘Continuity’ check – use it to check for shorts between strips. If you don’t have one then a visual check aided by good lighting (and a magnifier) should be fine
- Desoldering wick, along with some liquid flux. These two items are useful to open up any holes which are accidentally soldered over (preventing leads from passing through a hole).

For a successful build, we strongly recommend you assemble the *MKC* in the following sequence of steps:

1. Preparing the stripboard
2. Installing the wire links
3. Power indicator circuit (R1 and D1)
4. Power input circuit (USB BoB and J1)
5. Voltage regulator circuit (IC1, C1, C2)
6. Micromite circuit (IC2, R2, R3, C3, C4)
7. Female sockets (J2, J3, J4)
8. Case preparation
9. Finishing off (wire links from USB BoB).

Following the sequence above means that you can easily and methodically check progress, making it much easier to track down errors. It should also result in a working product when you complete the final step.

Step 1: Preparing the stripboard

The *MKC* is built on a piece of standard 0.1-inch stripboard, which will need to be prepared prior to any soldering. You will need a file, a pair of side-cutters, and a metal drill bit (or track-cutting tool).

Refer to Fig.2 and begin with a rectangular piece of stripboard, 24 strips wide, with 12 holes in each strip. If you’re obtaining this from a larger piece of stripboard, then you can either cut it out, or snap it off. Whichever method you use, ensure you ‘oversize’ by one hole, and then file down to the required 24 × 12 size.

Cutting stripboard (from a larger piece) is easily achieved with a pair of sharp side-cutters. Place the side-cutter blades over one end of the 13th row (not the 12th), and then carefully make a snip. This will result in a perforated cut appearing along that row of holes (much

like perforations along the edge of a postage stamp). Make another ‘snip’ at the other end of the 13th row (assuming the first snip didn’t result in the cut going all the way to the other edge). It will now be easy to break off the required (oversized) piece of stripboard. Repeat along the width should you need to reduce the width of your stripboard as well.

If you’d rather use the ‘snap’ method, then you may find it useful to securely ‘sandwich’ the required piece of stripboard between two pieces of wood, and snap off the ‘unrequired’ exposed piece. This will help prevent the ‘snap’ occurring in the wrong place potentially leaving you with an unusable piece of stripboard. Alternatively a workbench vice can prove useful. Repeat for width if necessary.

Whichever method is used, you will now need to file down the four edges so that they are all nice and smooth (rather than a row of jagged perforations) resulting in a rectangular piece of stripboard, which has 24 strips with 12 holes in each strip. (A good tip is to carefully file the corners to remove sharp points.)

To house the *MKC* in the recommended case, you will next need to cut away the two left corners, as shown in Fig.2 (viewed from the component side). To do this, carefully cut diagonally across each corner taking small ‘snips’ at a time; and then simply finish off with a file to create the shape shown. We do not recommend cutting along a row of holes (such as B1, B2, B3...); your cut

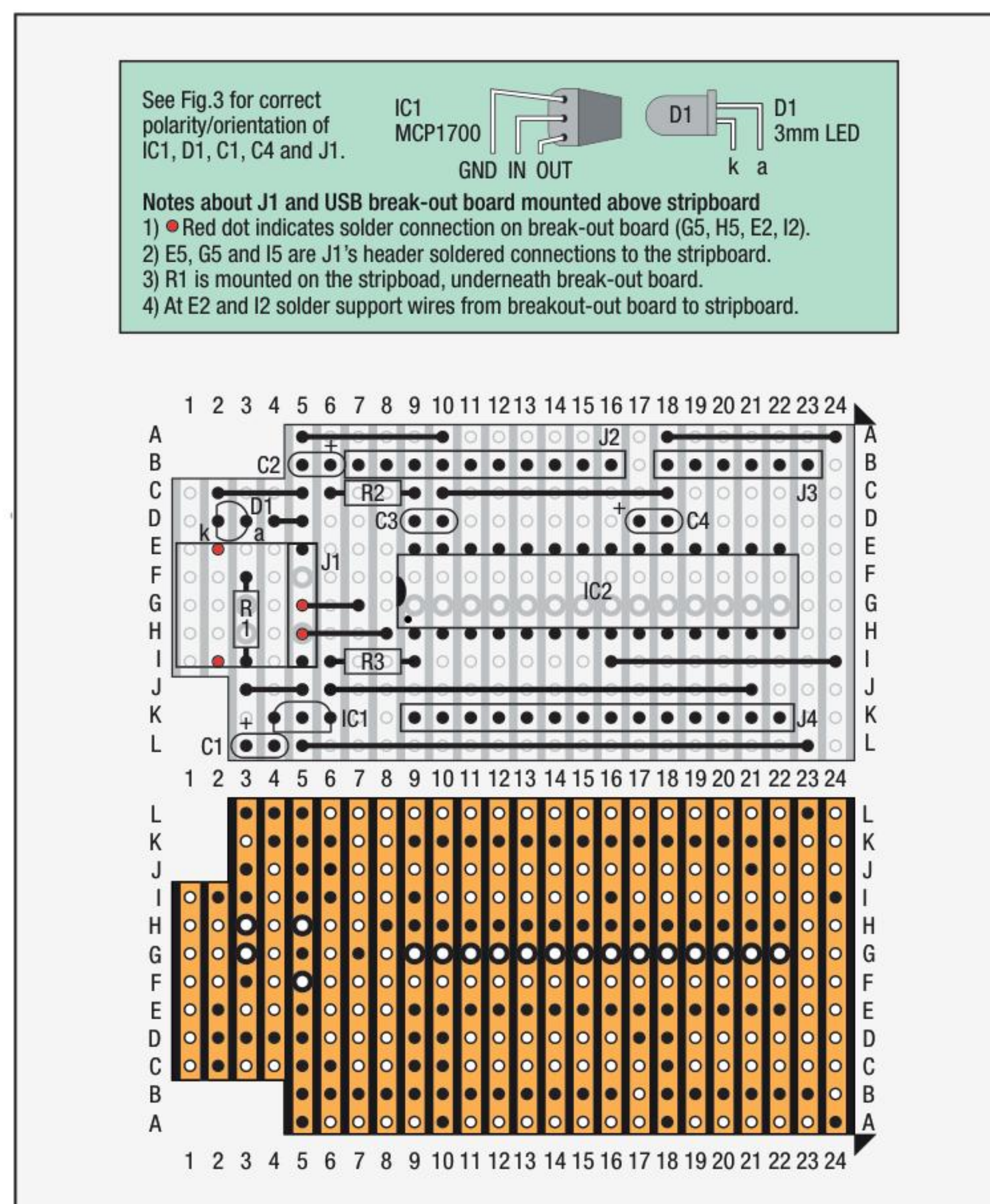


Fig.2. Stripboard layout for the *MKC*, (below) copper track view showing positions of where to cut tracks.

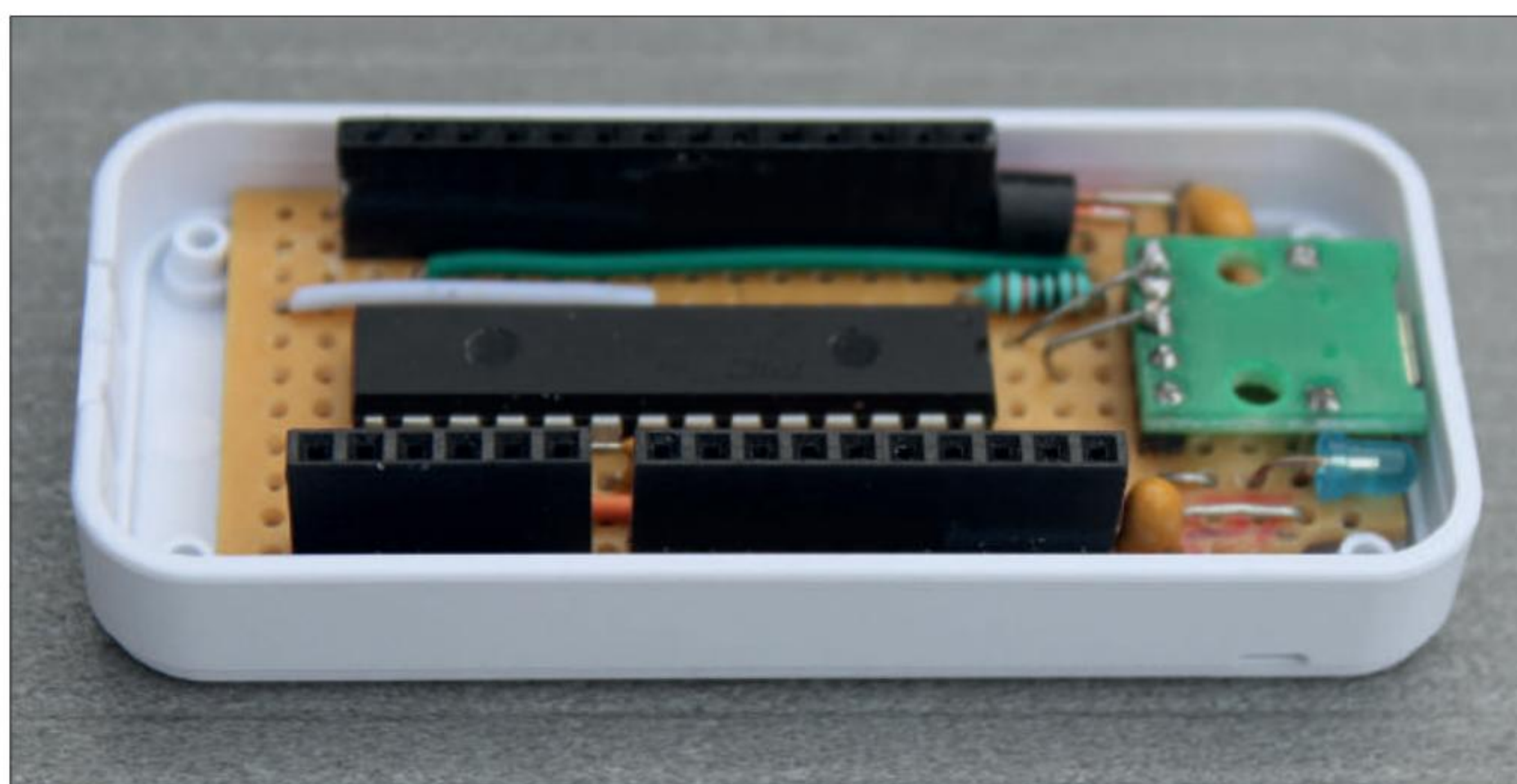
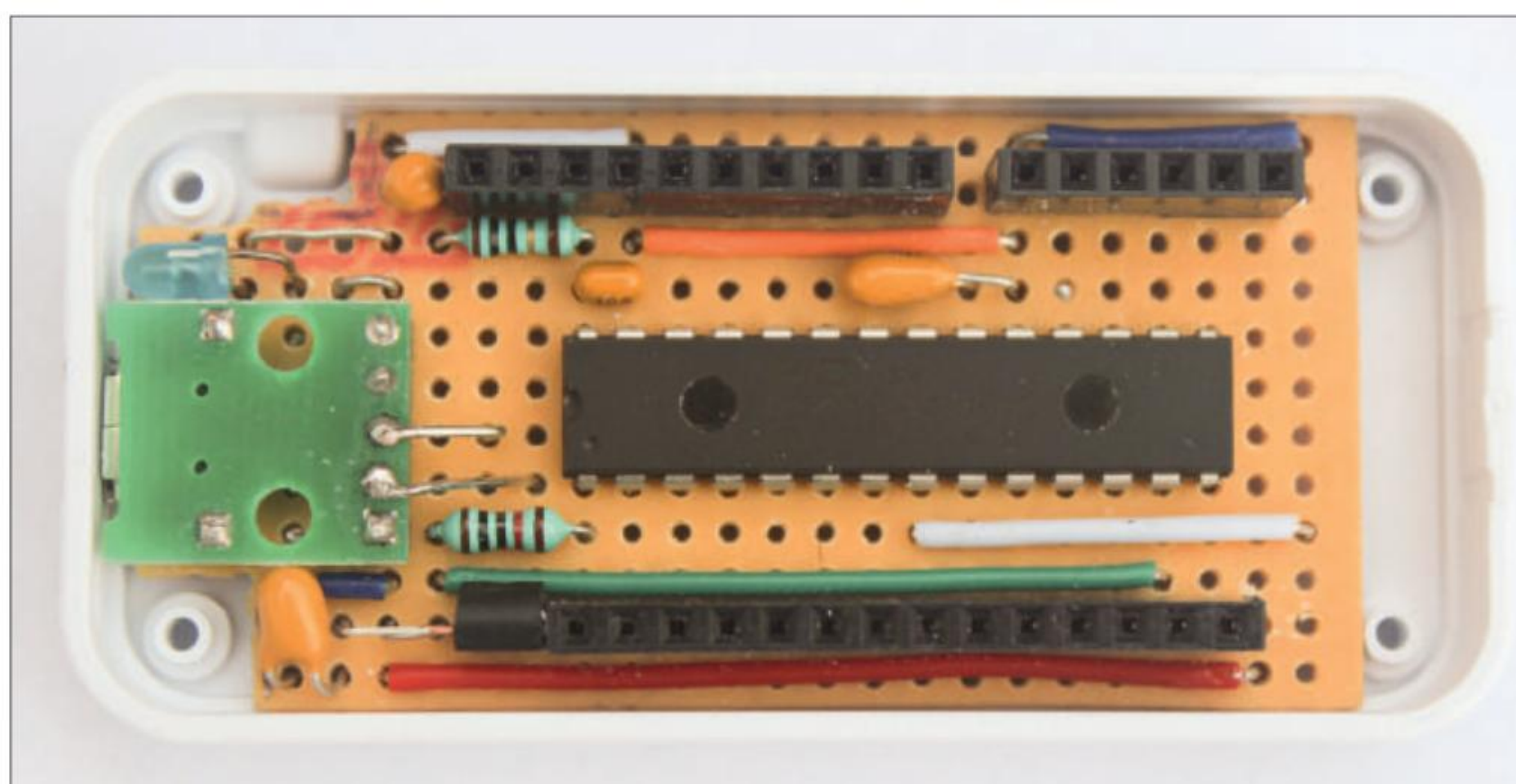
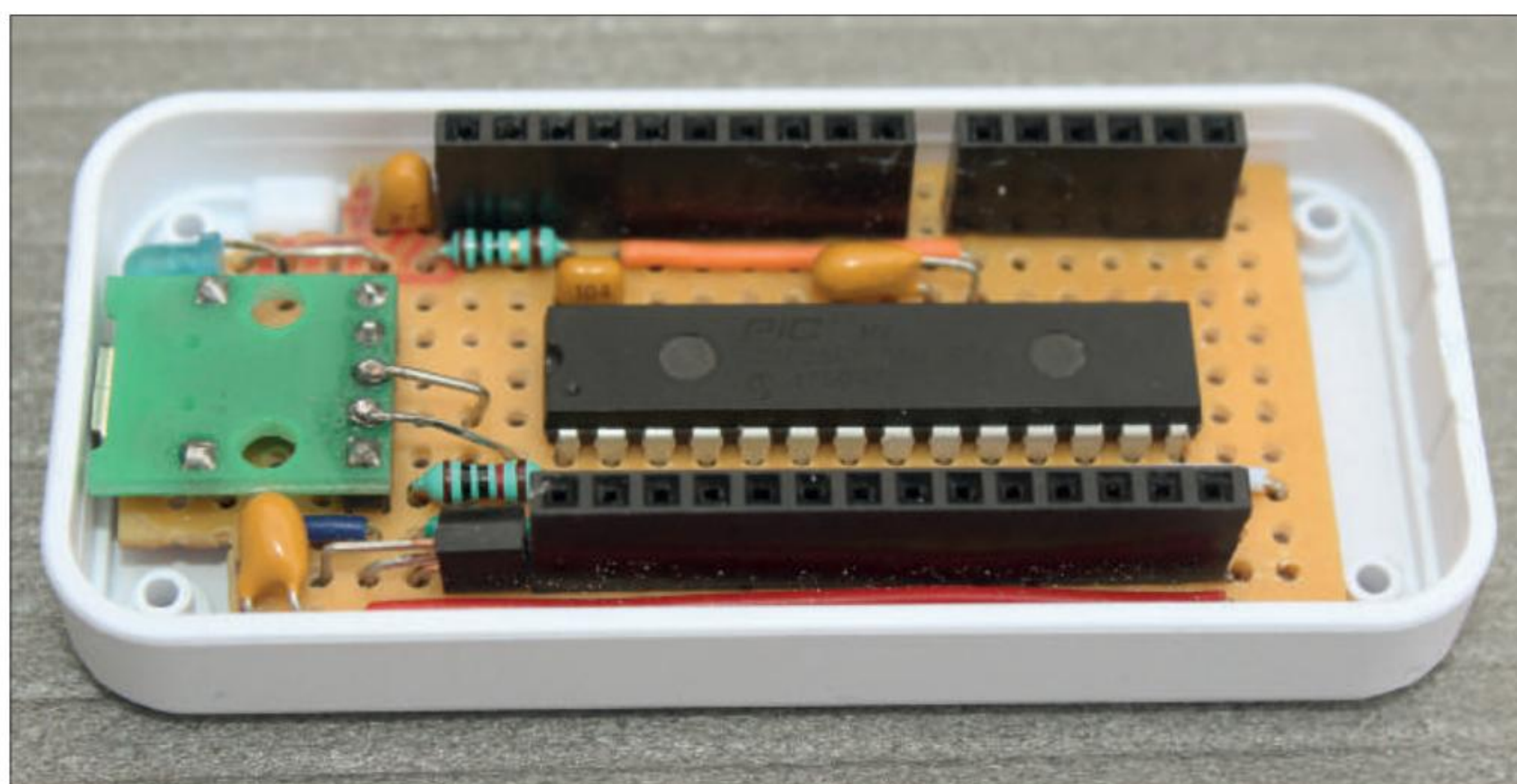
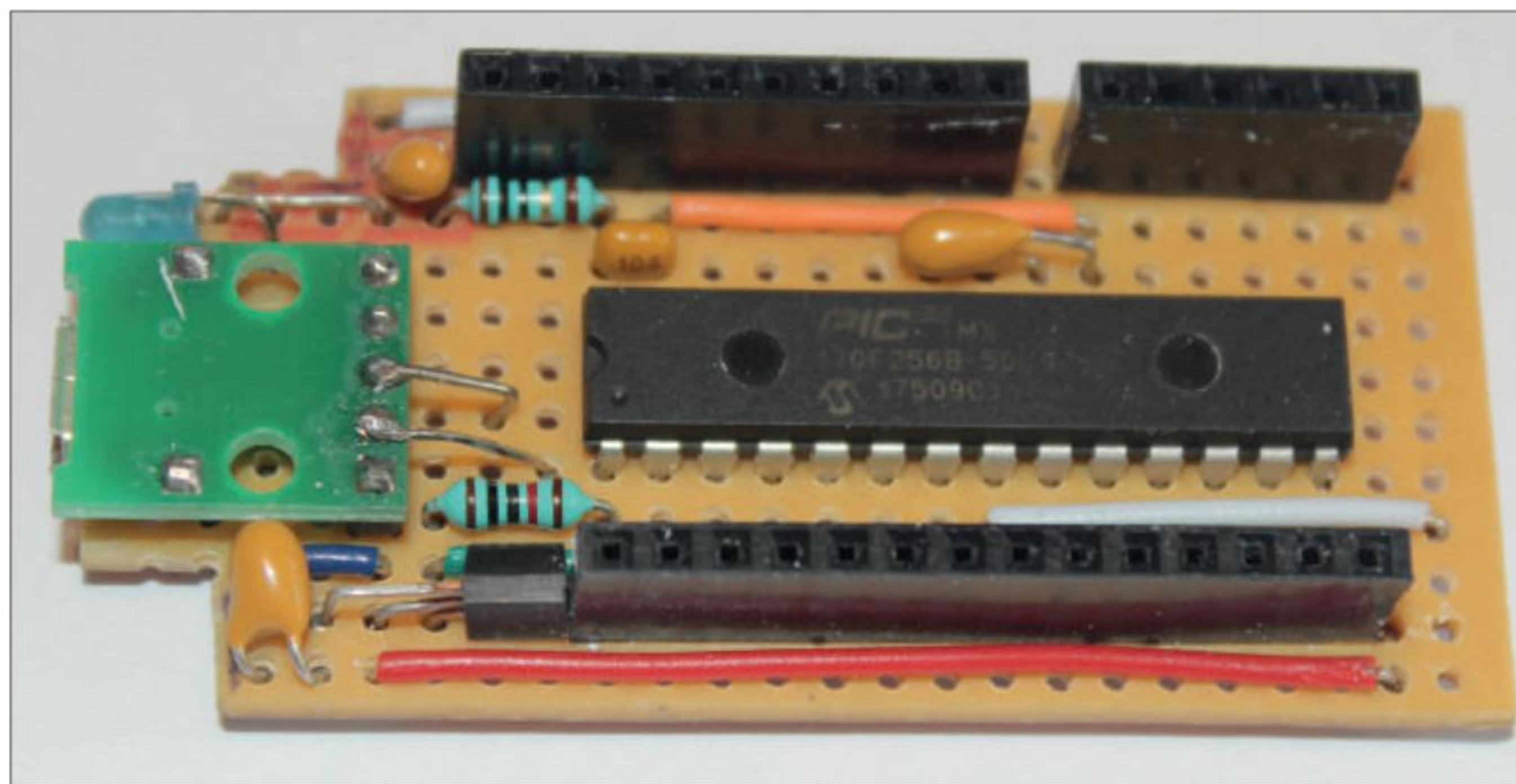


Fig.3. Various viewing angles of the assembled MKC board.

may split the stripboard, resulting in a piece of stripboard that is too small – you would then need to start all over again.

Once you have removed the two left corner sections, place the stripboard into the bottom part of the case and check it fits – if not, your stripboard may need a little more filing. Note that the bottom part of the case has provision to allow you to attach a chain or a wristband. This ‘loop’ should be positioned in the top left corner, and it is the reason why the top-left corner of the stripboard has a bigger section cut away. The board should then sit snugly between the case’s four screw pillars, and also rest flat on the ‘lip’ that you will see running around the base. Do not worry if the board appears loose at this stage. If the board is too big, or won’t fit in without applying force, then simply file the stripboard along the appropriate edge(s).

Next, you need to make cuts in the copper strips, as shown in the bottom diagram of Fig.2. The large black circles shows the positions of the 18 required cuts, as viewed from the copper-strip side. Before making any cuts, mark the locations of each cut point with a permanent marker. This lets you compare the cut positions with those in Fig.2. If you do make a mistake, then it is easy to mark the correct position (and obviously cross out the wrong position!). You will then have 18 marks that are correctly placed, making a useful ‘template’ for the cutting process. The old saying, ‘measure twice, cut once’ comes to mind here.

To cut the strips, use the tool referenced or a drill bit (3mm-5mm in size, but *not* a pointed woodwork or masonry bit). Position the bit over the the required hole, and turn it several times until the strip is clearly cut across its full width. If this proves too awkward then consider using a bigger bit. Be careful not to cut all the way through the stripboard – something that is possible if you have a sharp drill bit.

Do note that tiny strands of copper can remain attached to either side of a cut point and these risk a short to a neighbouring strip. We recommend you carefully inspect all cuts before proceeding with any soldering. A small flat bladed tool or screwdriver can be used to run up and down the space between each strip, which will usually dislodge any remaining strands. Alternatively, a piece of ultra-fine sandpaper can be used to gently rub down the cuts to carefully remove any remaining copper strands. Do not use your fingers to feel for burrs – you’ll cut yourself!

Take your time, check, double-check, and then check once again to ensure that everything is as it should be. Thorough checking at this stage will definitely help make the rest of the construction go smoothly.

If you have a multimeter, turn it to resistance (or ‘continuity check’) and for each strip ensure there are no short-circuits between neighbouring strips. Also, wherever you have cut a strip, place your probes either side of the cut to ensure the cut goes across the full width of the strip. Take your time and ensure you make these 18 cuts correctly.

Step 2: Installing the wire links

Now we can start soldering, and we will begin with the nine wire links, as shown in Fig.2. *Note: do not install the two wire links shown at locations G5-G7 and H5-H8.* These will be done towards the end of construction. Work on one wire link at a time, being careful to ensure you have the correct length and correct position for each link. The wire links sit on the plain side of the board, and pass through to the strip-side for soldering.

You do not have to use insulated wire (as shown in the photos), but do ensure that each link is as straight as possible to avoid them contacting any other links or components. After soldering each one, check to ensure you haven’t accidentally shorted out to a neighbouring strip. You can do this visually, but it is better to use a multimeter.

Step 3: Power indicator circuit

Next, we will solder in the 3mm Power LED (D1) and its current-limiting resistor (R1). You can use any colour LED that suits you – we like blue. As previously mentioned, R1 can be varied in value; 1k Ω gives good brightness for a blue LED driven at 5V. The LED is a polarised component, so it must be soldered the right way round. The LED has two leads, a longer positive lead (anode) and shorter negative lead (cathode). Both leads need bending into shape prior to mounting it onto the stripboard. If you have access to a pair of long-nose fine pliers then these will allow you to get nice sharp bends; otherwise simply bend the leads carefully by hand.

Once you have identified which lead is which, bend them into the shape as shown in the top diagram in Fig.2. Then, referring to the middle diagram in Fig.2, and the photos in Fig.3, position the LED into the correct two holes (D2 and D3). The tip of the LED should be roughly in line with the left-hand edge of the stripboard. It must not stick out too much beyond the edge, otherwise the finished board won’t fit in the recommended case (if necessary, straighten the leads, then re-bend them so that the LED fits correctly). Once you are happy with the positioning of the LED, carefully solder it. Now bend the two leads on R1 and position it in F3 and I3. Resistors are not polarised and can be mounted either way around. However, it is critical

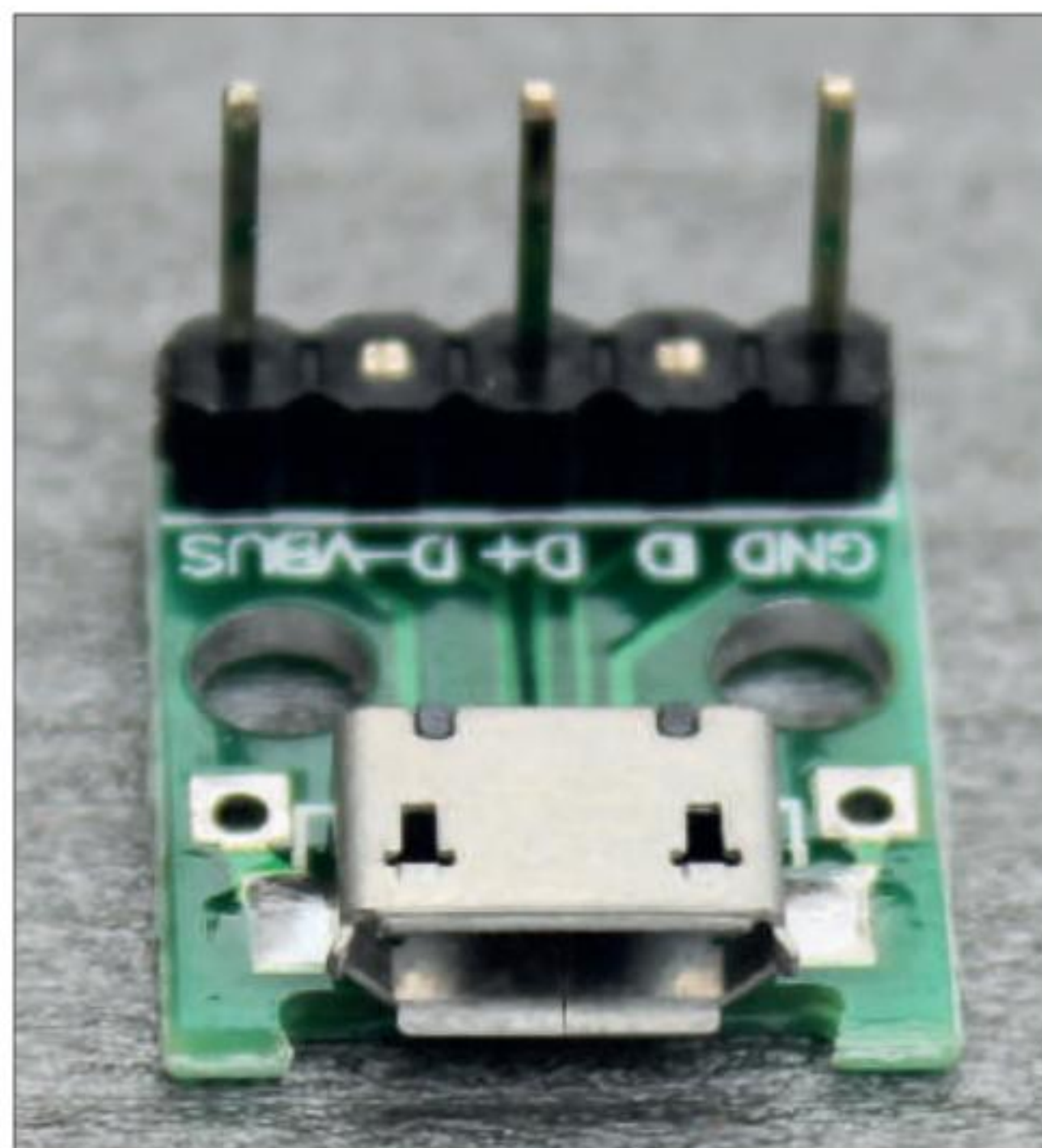


Fig.4. Prepare the USB Break-out board header pins as shown here.

that this resistor lies flat on the board (we will be mounting the USB BoB over it). If you have R1 in the correct position you will see two track cuts between its two leads. Solder R1 and snip of the excess leads (keep these two off-cuts for the next step). Perform the usual check for shorts around new solder joints.

Step 4: Power input circuit

The USB BoB is mounted upside-down and sits over R1. Therefore, do a final check to ensure that the correct value LED resistor is in place. To prepare the USB BoB, solder a 5-pin header (long pins facing upwards) onto the BoB, and then cut pins 2 and 4 (ID, and D-) as shown in Fig.4. Now invert it, and place it into the correct position, soldering the three pins (at hole positions E5, G5 and I5) onto the stripboard. As a check, the three pins that need soldering should be either side of the two cuts in strip 5. To provide added rigidity for the USB socket, two ‘support-wires’ can be soldered from the two small holes on the BoB (Fig.4) to E2 and I2 (as can be partially seen in the photos in Fig.3). Use the two off-cuts from R1 (previous step) for this purpose, ensuring the leads are as straight as possible. If you didn’t keep those from R1, simply use two other off-cuts. Perform the usual checks for shorts.

Now it’s time to perform a quick test. Use a 5V micro-USB power source (such as a phone charger, or a battery pack) and plug it into the BoB’s micro-USB socket. If everything is OK you should see the LED light up. If not then remove power, and check things over, including:

- Ensure the power source is switched on, or the battery pack is charged
- Check the positions of D1, R1, and J1
- Check for shorts around solder joints.

If all the above is OK, then it is possible that you have made an error with the LED (remember it is polarised). If you have a multimeter, then set it to ‘Voltage’, power

up the MKC, and measure the voltage across the two ‘end pins’ on the BoB; ie, the two end pins on J1. This should read 5V (or very close to 5V). If it does, but the LED is still off, then you probably have the LED inserted the wrong way around. However, if you do not read 5V, then there is either an issue with your power source, or there is a short somewhere. If you can’t find any problem(s), then take a break and come back later with fresh eyes.

Step 5: Voltage regulator circuit

Assuming that the LED lights up when you power the MKC, we can now install the voltage regulator (IC1) and its two associated 10 μ F tantalum capacitors (C1 and C2). Ensure you remove power before continuing.

Start with the voltage regulator. We will need to bend the three leads into shape prior to mounting it onto the stripboard. Refer to the top diagram in Fig.2, bend the ‘OUT’ lead as close as possible to the ‘body’ of the voltage regulator. Ideally, use needle-nose pliers to avoid putting too much stress on the point where the lead comes out of the body. Shape the other two leads as shown so that the end result can be mounted in K4, K5 and K6. The ‘body’ should be sitting over holes K7 and K8. It must not be over K9, otherwise it will not be possible to mount socket J4. Once you have the correct positioning for the voltage regulator, go ahead and solder it in.

The two 10 μ F tantalum capacitors (C1 and C2) are polarised meaning that it is important to get them the correct way around before soldering. The longer lead is the positive lead; it is also indicated on the body of the capacitor with a ‘+’ mark. Be careful not to assume the marking is the negative lead (as it is with electrolytic capacitors). C2 (nearest the top-left corner) is simply inserted with the correct orientation as shown in Fig.2 (positive lead in hole position B6, negative lead in B5). Capacitor C1 (bottom left corner) needs to have its two leads pre-shaped prior to insertion (bent at right angles as can be seen in the photos in Fig.3). With the positive lead in hole L3, and the body flat against the stripboard, solder C1 into place. Now do the usual checks for shorts.

If you have a multimeter, then set it to ‘Voltage’, power up the MKC and check the LED still lights up. If not, remove power and check for shorts once again. With the LED lit, measure the voltage across wire links ‘A18-A24’ (0V) and ‘J6-J21’ (3.3V). You can do this by probing at any ‘exposed’ part on each wire link. Check for 3.3V across these two wire links. If you don’t read approximately 3.3V then power down and check for shorts. Do ensure the flat part of the voltage regulator faces the bottom edge of the board.



Fig.5. Using the assembled board to help mark the locations of the LED and USB cut-outs required in the end of the case.

Step 6: Micromite circuit

With the power removed, it is now time to solder in the 28-pin Micromite (IC2). We are not using an IC socket in this design; this is so we can fit the assembled product snugly into the recommended case. If you are not going to mount the finished item into the case, then we recommend using a 28-pin IC socket. It is critical to ensure that you get the Micromite inserted into the correct position, and also with the correct orientation. Pin 1 needs to be towards the lower left, in hole H9 (pin 1 is indicated by a small indent on the top of the IC). You will probably need to bend the IC pins slightly inwards so that the two rows of pins on the Micromite align up with the holes in the stripboard. This can be achieved by using a small pair of pliers, or better still, by laying one row of pins on a hard work surface, and then applying gentle pressure to bend all the pins along one edge in a single action. Repeat for the other row of pins so that both rows are bent inwards by a small amount. With the Micromite inserted correctly, turn the board over and visually check that all 28 pins have come through to the strip side. Ensure you get this right, it will be extremely hard to remedy later ('check twice, solder once!'). Take your time soldering all 28 pins, ensuring you don't introduce any shorts. It's a good idea to solder one corner pin first, and then the pin diagonally opposite it. Then turn the unit over and check that the Micromite IC is sitting flat against the stripboard. If it isn't, simply reheat each of the two soldered corner pins while applying pressure on the IC to push it down onto the stripboard. Once it is flat, solder the remaining 26 pins.

There are four passive components that we need to solder to complete the Micromite circuit (R2, R3, C3, and C4).

Bend the leads on the 10Ω resistor (R2) and insert it into holes C6 and C9. Check position is correct, then solder it in. Repeat with the 10kΩ resistor (R3) at I6 and I9.

The smaller 100nF capacitor (C3) is non-polarised and is simply soldered at D9 and D10.

The final 10μF tantalum capacitor (C4) needs preparing prior to mounting. It is polarised, so identify the longer (marked) positive lead, which will end up in D17. The shape of the bends need to be physically the same as the LED, so refer

to the top diagram in Fig.2, and the photos in Fig.3 to help prepare the capacitor. Make the two bends as in the diagram for the LED, but with the capacitor's longer positive lead formed

as shown for the LED's cathode (k). Then mount C4 at D17 (+ve) and D18 (-ve), check it, and solder it.

Perform the usual checks for shorts, then power up to ensure the LED still lights. If so, then all is well and we can move on. However, if the LED no longer lights, do the usual checks.

Step 7: Female sockets

Next, remove power, and insert the three sockets (do not solder at this stage!). Note: the micromite.org kit contains a 15-way socket for use as the 14-way socket (J4) – you will need to cut off one end pin (either end is fine). To do this, gently cut through the 15th pin's plastic and the metal part will fall away leaving part of the plastic body still attached, which you can now carefully file away.

The 14-way socket lines up perfectly with 14 pins on the bottom row of the IC. However, the shorter 6-way socket extends one hole beyond the right-hand side of the IC, and the 10-way extends two holes to the left of the IC. This will result in a one-hole-gap between the two uppermost sockets. If this is all correct, solder in the three sockets. Start by soldering the end pins of each socket, and ensure all three sockets are nicely lined up (and vertical). Any necessary adjustments can then easily be made just by heating the relevant end pin, and rechecking alignment. Once you're happy that everything is straight, solder all the remaining pins; again, be careful not to introduce any shorts.

Now perform another quick test to ensure the Power LED still lights up when a power source is connected and switched on. If it doesn't, check for shorts.

Step 8: Case preparation

The case will need some cut-outs to allow the assembled board to fit nicely. There are two cut-outs made at the end of the base (for the USB socket and the Power LED, see Fig.5). The lid has three cut-outs for the three sockets (see Fig.6).

Starting with the base, take the assembled module and rest the USB end of it on the left-hand edge of the base, as shown in Fig.5. Now, using a pencil, mark the vertical edges of the USB socket on the outside of the case. Also mark the central vertical position of the LED.

For best effect, drill a tiny hole (no bigger than 1mm) to allow the LED's light

to shine through with a nice 'pin point' when the MKC is powered. This is a much neater finish than having an LED stick out through a 3mm hole!

Various techniques can be applied to cut the hole for access to the USB socket. We used a 3mm drill bit and carefully drilled a row of holes. Then we used a sharp knife to slowly shave off small pieces of ABS plastic to obtain the 'oval' shape required. Once this USB cut-out is made, the board should fit into the case and you can then try inserting a micro-USB lead into the BoB. Continue shaving off tiny bits until the USB plug fits nice and securely. Take your time here to obtain a nice looking finish.

Next, the lid (Fig.6) – ensure you have the board resting correctly in the base of the enclosure. Now present the lid and mark the left and right hand positions of each of the three female sockets. Then position the lid to mark the top and bottom positions of all three rows of sockets. Using a ruler and sharp pencil, it is possible to draw three rectangular outlines of where we need to make the cut-outs. Use the lip on the top-edge of the lid to ensure the cut-outs are parallel (ie, straight). Now drill a row of 3mm for each cut-out. Tidy up with a sharp knife, or better still a file – a nail file gives a nice finish.

Don't worry if your cut-outs are a little over sized or untidy. You can always print a top panel label, and stick it on the lid to hide cut-out errors. A label could include useful information such as pin identifications. As you can see in the *Part 1* photos, we printed a logo onto paper, made three cut-outs (with knife and metal ruler) and stuck it on the lid to cover up our poor first attempt at cutting socket holes.

Once you think you have the cut-outs made, try placing the lid on the base. Chances are that on first attempt it will not fit over the three sockets and you will have to file/shave away more plastic. Again, take your time and you will end up with a pleasing result.

When you have the lid fitting nicely, power up your MKC and you should see the LED 'glowing' through the tiny hole on the side of the case. If so, then congratulations – you are almost done.

Step 9: Finishing off

There are two final wire links to solder, running from the upper side of the BoB to the stripboard. Refer to Fig.2, you can see the two wire links between G5-G7, and H5-H8. An important point here is you need to keep to a minimum the height of the joints on top of the USB BoB (to ensure the lid will fit the case properly).

Once these final two wire links are soldered, do one last check. Power your MKC and check that the Power LED lights.

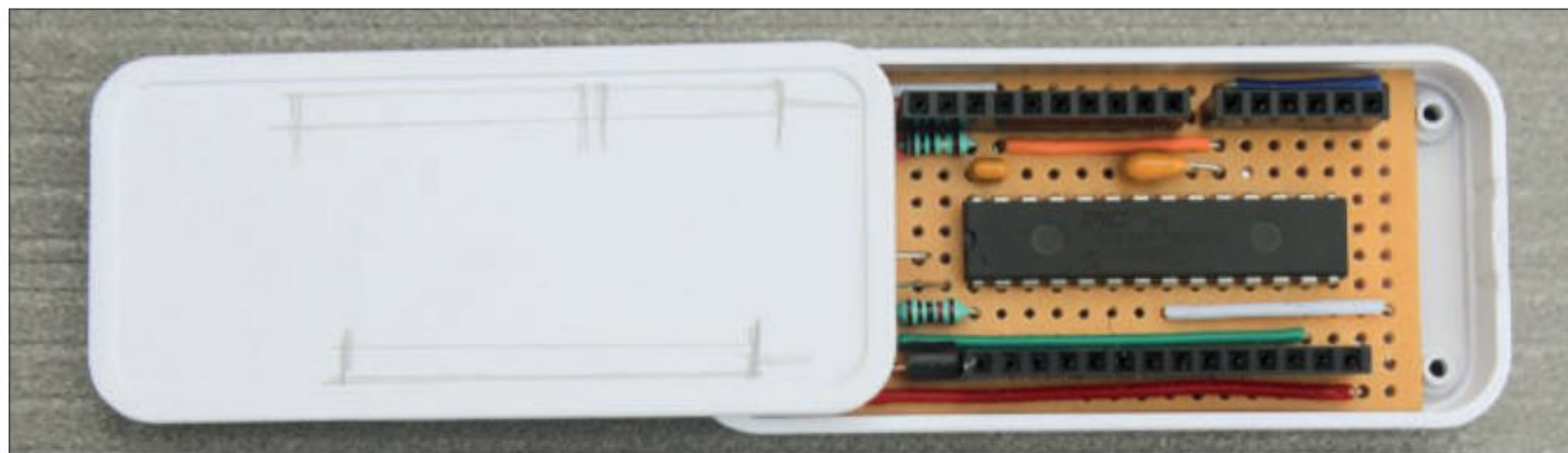
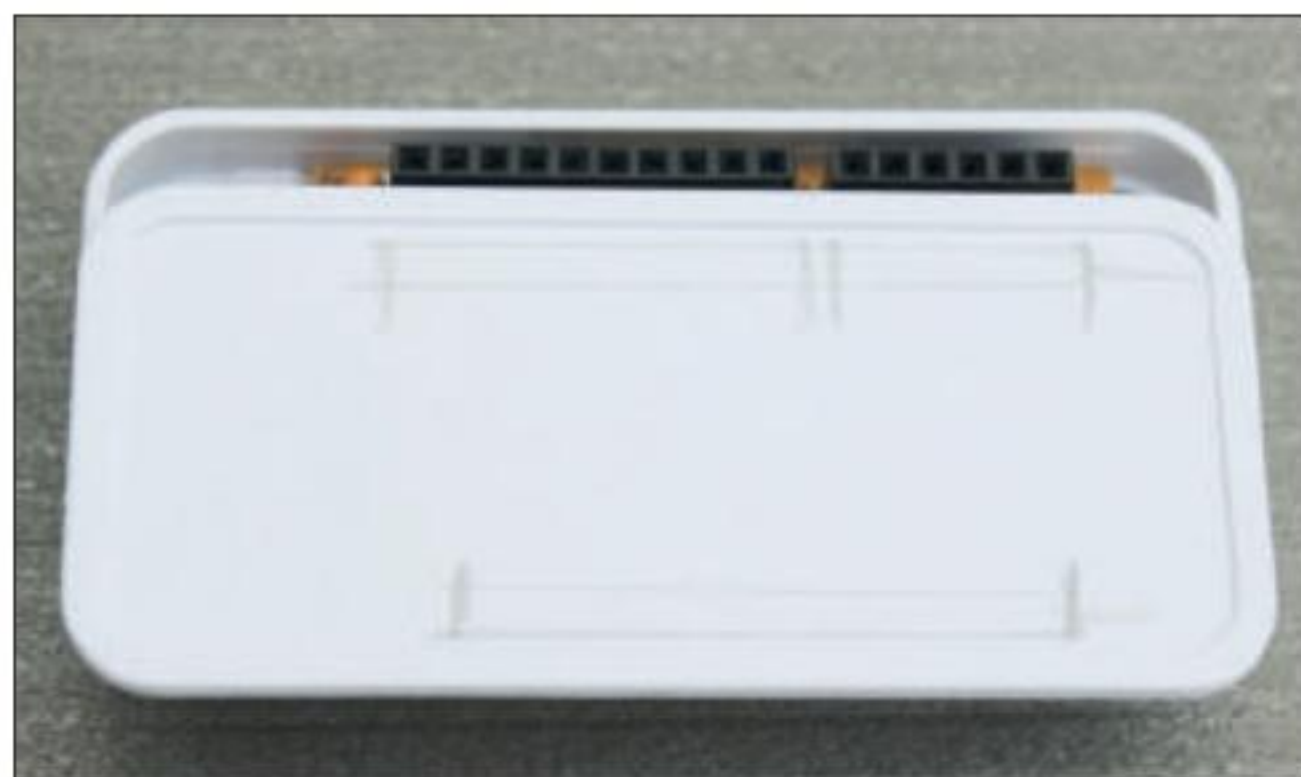


Fig.6. Use the assembled board to mark the positions of the three cut-outs in the lid.

Now place the completed module into the base of the case (ensuring the 'keyring loop' is in the top-left corner). Fit the lid securely with the four supplied case screws. Note that the board just 'sits' inside the case and is not screwed down; however, the shape of the board means it fits snugly in place and will not move. If you have purchased the optional Silicone protective sleeve, then place it around the case ensuring that the open end of the sleeve is at the USB end (to allow access to the USB socket).

Congratulations – you've now completed your *Micromite Keyring Computer*!

Testing

If you purchased a **micromite.org** kit, then you can now perform a very useful test to ensure that your *MKC* is 100% fully functional. If, however, you have sourced your own 'blank' 28-pin PIC, then you will be unable to perform the following test yet. In that case, you can skip the next section and wait for next month's assembly of the *Development Module (DM)* article.

Kit Micromites come pre-loaded with a test program that will automatically run as soon as the *MKC* is powered up. This test program first sets all of the 19 input/output pins as outputs, and then performs an endless loop of switching each output in turn, 'on' briefly, and then 'off'. The 19 outputs we need to check are numbered on sockets J2, J3 and J4 in the circuit diagram (see Fig.1).

You can build a very effective test circuit using just an LED and a single resistor (with a value between 470Ω and $1k\Omega$) – see Fig.7. Solder the LED's longer (+ve) lead to one end of the resistor (the same circuit configuration as R1 and D1 in Fig.1). Then insert the LED's shorter lead (–ve) into 0V in the left-hand position (B18) of socket J3 (see Fig.1). Solder the other end of the resistor to a 'wire probe', which we will use to test each of the 19 numbered outputs on sockets J2, J3, and J4. This test-circuit can alternatively be built on a spare piece of stripboard, or better still, on breadboard. It's a good idea to use insulation tape to cover most of the 'exposed' leads of your LED tester circuit'. This will reduce the risk of accidental short-circuits, which could damage the Micromite.

Insert the wire probe into the right-hand position of socket J3 (B23). This is a 5V output, and will confirm your test circuit is working correctly, or not! If the test LED lights, then your test circuit is working correctly. If not, then first check that your *MKC* is powered (the *MKC*'s Power LED should be lit), and then check that you have the test LED the correct way round in your test circuit (remember, an LED is a polarised component and will not work if it is wired the wrong way round).

When you have your simple test circuit working, test each Micromite output in turn, starting with socket J4 position '2' (K10) (refer to Fig.1). You should see the LED briefly flash. Leave the test probe connected to '2' and ensure the test LED

flashes periodically. Now remove the test probe from '2' and move it into position '3' (on socket J4). Check again that the test-LED flashes periodically. Work your way methodically around the remaining 17 numbered locations on sockets J4, J3 and finally J2).

If any of the numbered positions on these three sockets fails to flash the test-LED, then it means one of three things:

- That numbered pin on the 28-pin MicroMite (or relevant female socket) is shorted to a neighbouring track
- That numbered pin on the 28-pin Micromite (or relevant female socket) is not soldered; ie, open circuit
- The Micromite does not have the Test Program installed.

Remove power, unscrew the case lid, and take out the *MKC*. Start with a visual check on the solder side of the stripboard around the pin-number(s) that failed to flash.

Useful test info

Do ensure you start at position '2', working up to finish at position '26'. If any numbered location fails to flash the test LED, then move the test probe to the next location (ie, the location with a higher number than that which has just failed). Now check to see if this new location flashes the LED. If it does, then this means the previously failed number is open-circuit somewhere. If, however, the new location also fails to flash the test LED, then it is likely that these two locations are shorted out with each other.

If you have taken your time during assembly, and have followed these instructions with care, then you should see that all 19 numbered locations flash the test LED in turn meaning everything is working as it should.

Next month

That's all for this month. In the April issue we'll build the *Development Module* and test the whole system. Don't forget that all parts, including the case, are available from: **micromite.org** and do follow our new blog: **micromite.org/blog**

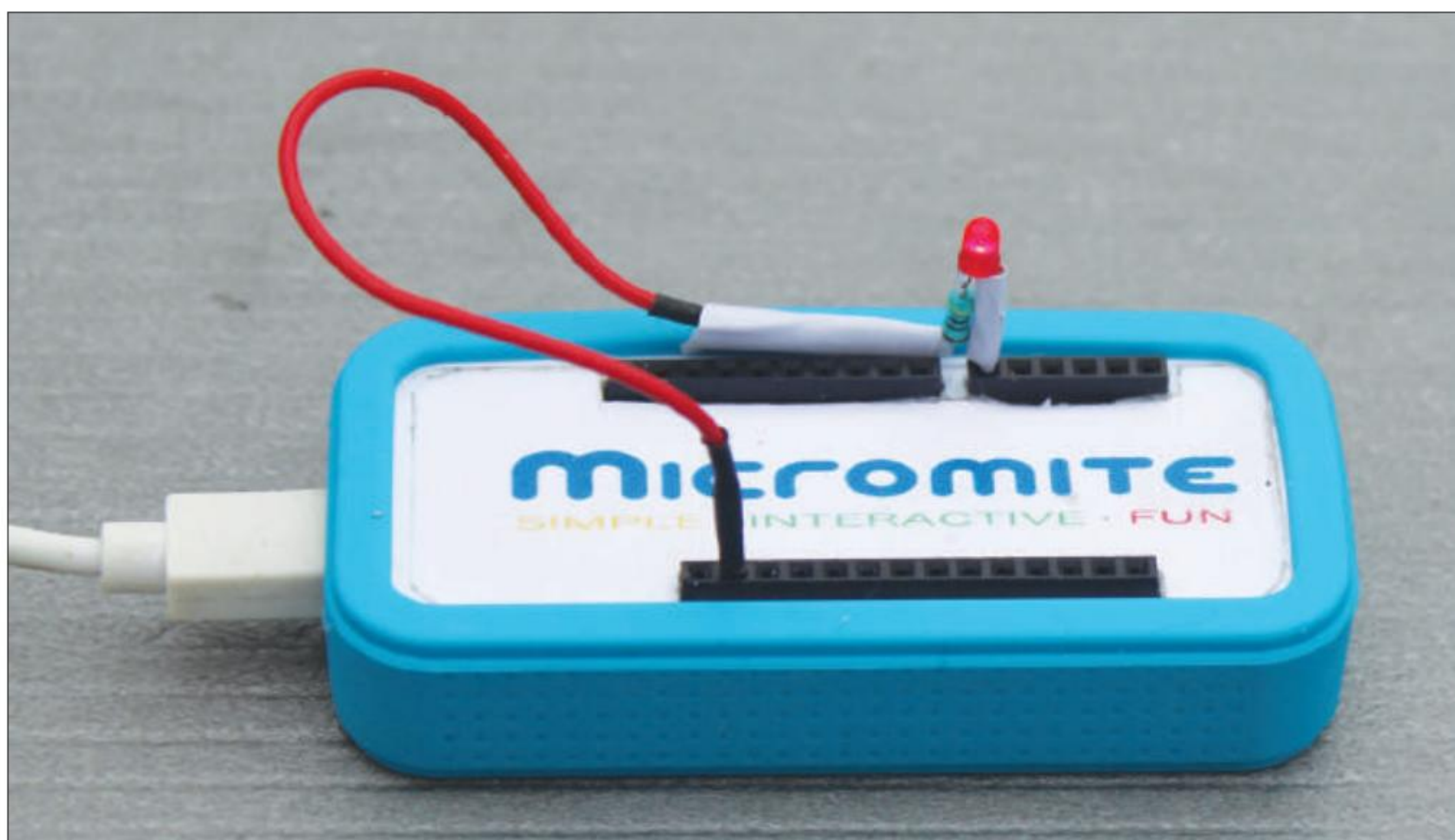
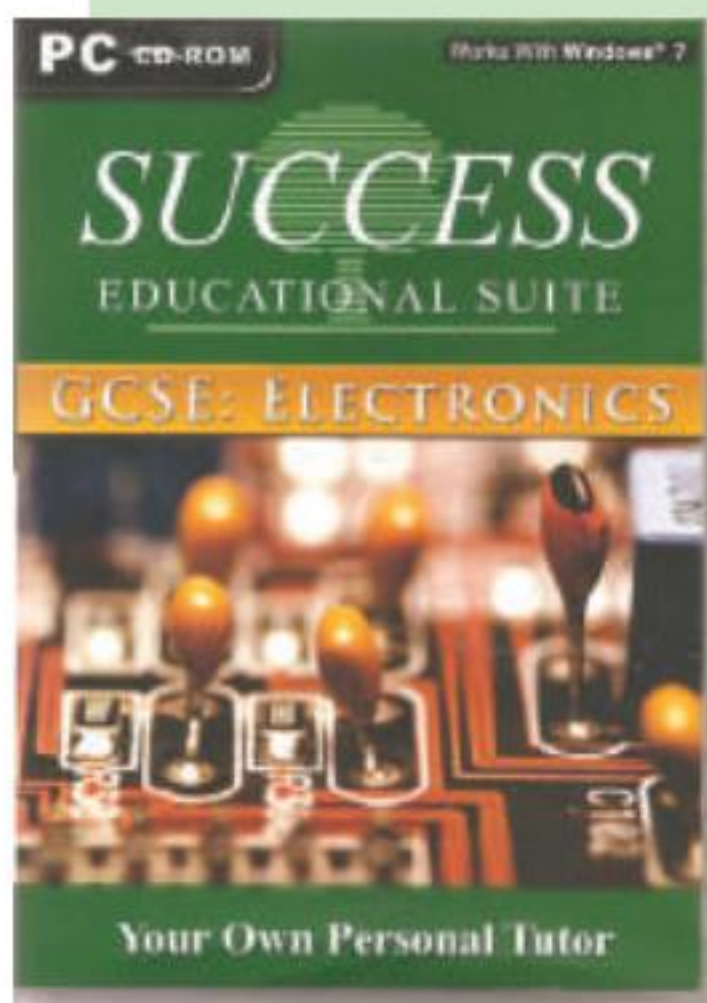


Fig.7. Using the *MKC* tester circuit – a resistor and an LED.

Questions? Please email Phil at:
contactus@micromite.org

EPE IS PLEASED TO BE ABLE TO OFFER YOU THESE ELECTRONICS CD-ROMS



£12.50
inc. VAT and P&P

GCSE ELECTRONICS

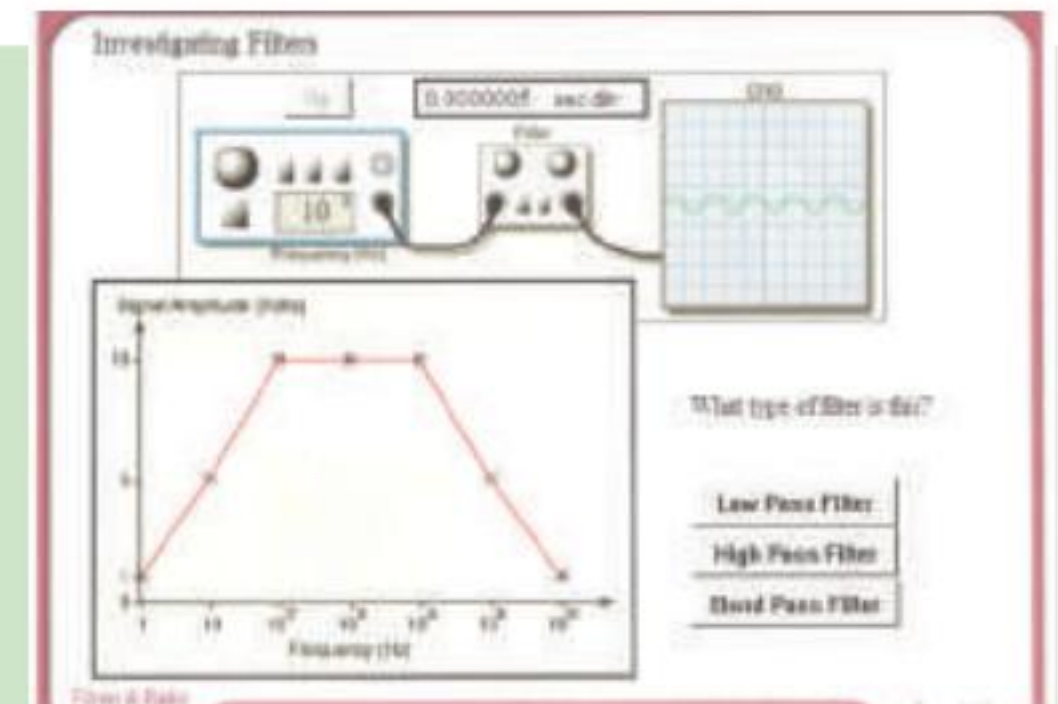
Suitable for any student who is serious about studying and who wants to achieve the best grade possible. Each program's clear, patient and structured delivery will aid understanding of electronics and assist in developing a confident approach to answering GCSE questions. The CD-ROM will be invaluable to anyone studying electronics, not just GCSE students.

- * Contains comprehensive teaching material to cover the National Curriculum syllabus
- * Regular exercises reinforce the teaching points
- * Retains student interest with high quality animation and graphics
- * Stimulates learning through interactive exercises
- * Provides sample examination questions with model solutions
- * Authored by practising teachers
- * Covers all UK examination board syllabuses
- * Caters for all levels of ability
- * Useful for self-tuition and revision

SUBJECTS COVERED

Electric Circuits – Logic Gates – Capacitors & Inductors – Relays – Transistors – Electric Transducers – Operational Amplifiers – Radio Circuits – Test Instruments

Over 100 different sections under the above headings



CIRCUIT WIZARD

Circuit Wizard is a revolutionary software system that combines circuit design, PCB design, simulation and CAD/CAM manufacture in one complete package. Two versions are available, Standard or Professional.

By integrating the entire design process, Circuit Wizard provides you with all the tools necessary to produce an electronics project from start to finish – even including on-screen testing of the PCB prior to construction!

- * Circuit diagram design with component library (500 components Standard, 1500 components Professional)
- * Virtual instruments (4 Standard, 7 professional)
- * On-screen animation
- * Interactive circuit diagram simulation
- * True analogue/digital simulation
- * Simulation of component destruction
- * PCB Layout
- * Interactive PCB layout simulation
- * Automatic PCB routing
- * Gerber export
- * Multi-level zoom (25% to 1000%)
- * Multiple undo and redo
- * Copy and paste to other software
- * Multiple document support

This software can be used with the **Jump Start** and **Teach-In 2011** series (and the **Teach-In 4** book).
Standard **£61.25** inc. VAT. Professional **£75** plus VAT.

From
£49.00

TINA Design Suite V11

Analogue, Digital, Symbolic, RF, MCU and Mixed-Mode
Circuit Simulation and PCB Design with TINA

TINA Design Suite V11 is a powerful yet affordable software package for analysing, designing and real time testing analogue, digital, MCU, and mixed electronic circuits and their PCB layouts. You can also analyse RF, communication, optoelectronic circuits, test and debug microcontroller applications.

Enter and analyse any circuit up to 100 nodes (student), or 200 with the Basic (Hobbyist) version within minutes with TINA's easy-to-use schematic editor. Enhance your schematics by adding text and graphics. Choose components from the large library containing more than 10,000 manufacturer models. Analyse your circuit through more than 20 different analysis modes or with 10 high tech virtual instruments.

Present your results in TINA's sophisticated diagram windows, on virtual instruments, or in the live interactive mode where you can even edit your circuit during operation.

Customise presentations using TINA's advanced drawing tools to control text, fonts, axes, line width, colour and layout. You can create and print documents directly inside TINA or cut and paste your results into your favourite word processing or DTP package.

TINA includes the following Virtual Instruments: Oscilloscope, Function Generator, Multimeter, Signal Analyser/Bode Plotter, Network Analyser, Spectrum Analyser, Logic Analyser, Digital Signal Generator, XY Recorder.

This offer gives you a CD-ROM – the software will need registering (FREE) with Designsoft (TINA), details are given within the package.

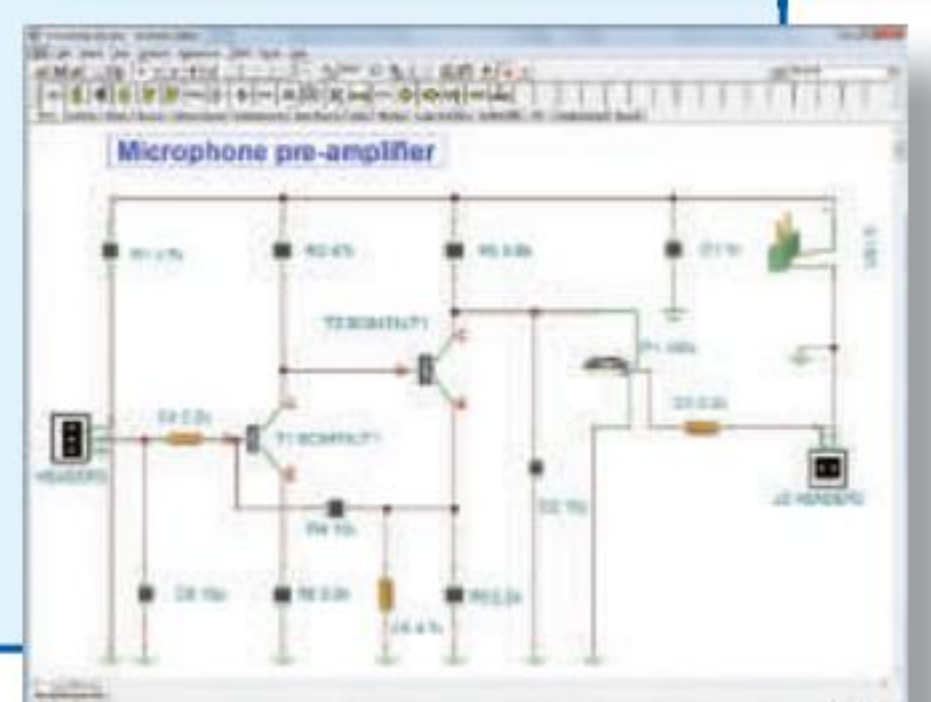
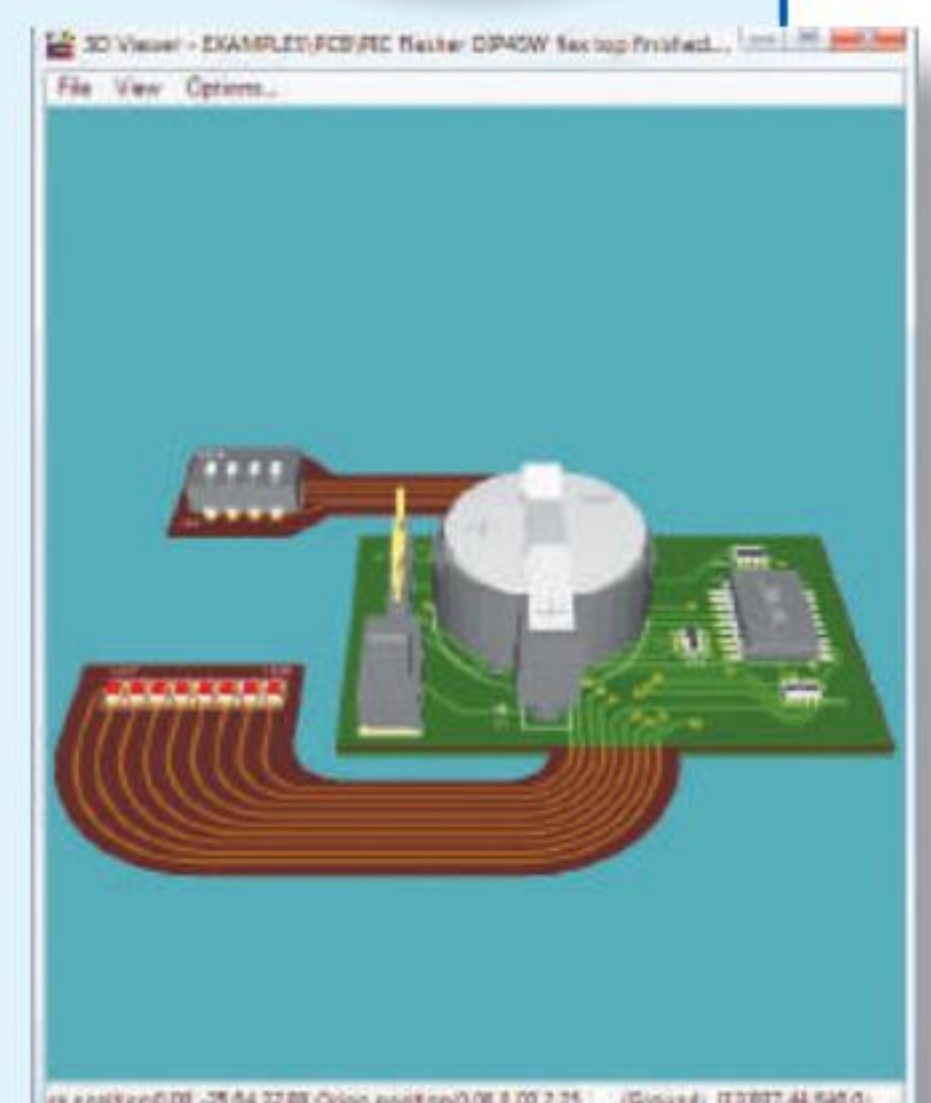
Get TINA Basic V11 (Hobbyist) for £129 or Student V11 version for £49

Prices include VAT and UK postage

+ get a 1 year free subscription for TINACloud the breakthrough cloud version of TINA which you can run on most operating systems and computers, including PCs, Macs, thin clients iPads and other tablets – even on many smart phones, smart TVs and e-book readers.

To order please either fill out and return the order form, or call us on **01202 880299**

Alternatively you can order via our secure online shop at: **www.epemag.com**



PICmicro TUTORIALS AND PROGRAMMING

HARDWARE

PICmicro Multiprogrammer Board and Development Board

Suitable for use with the three software packages listed below

This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories



£118 including VAT and postage

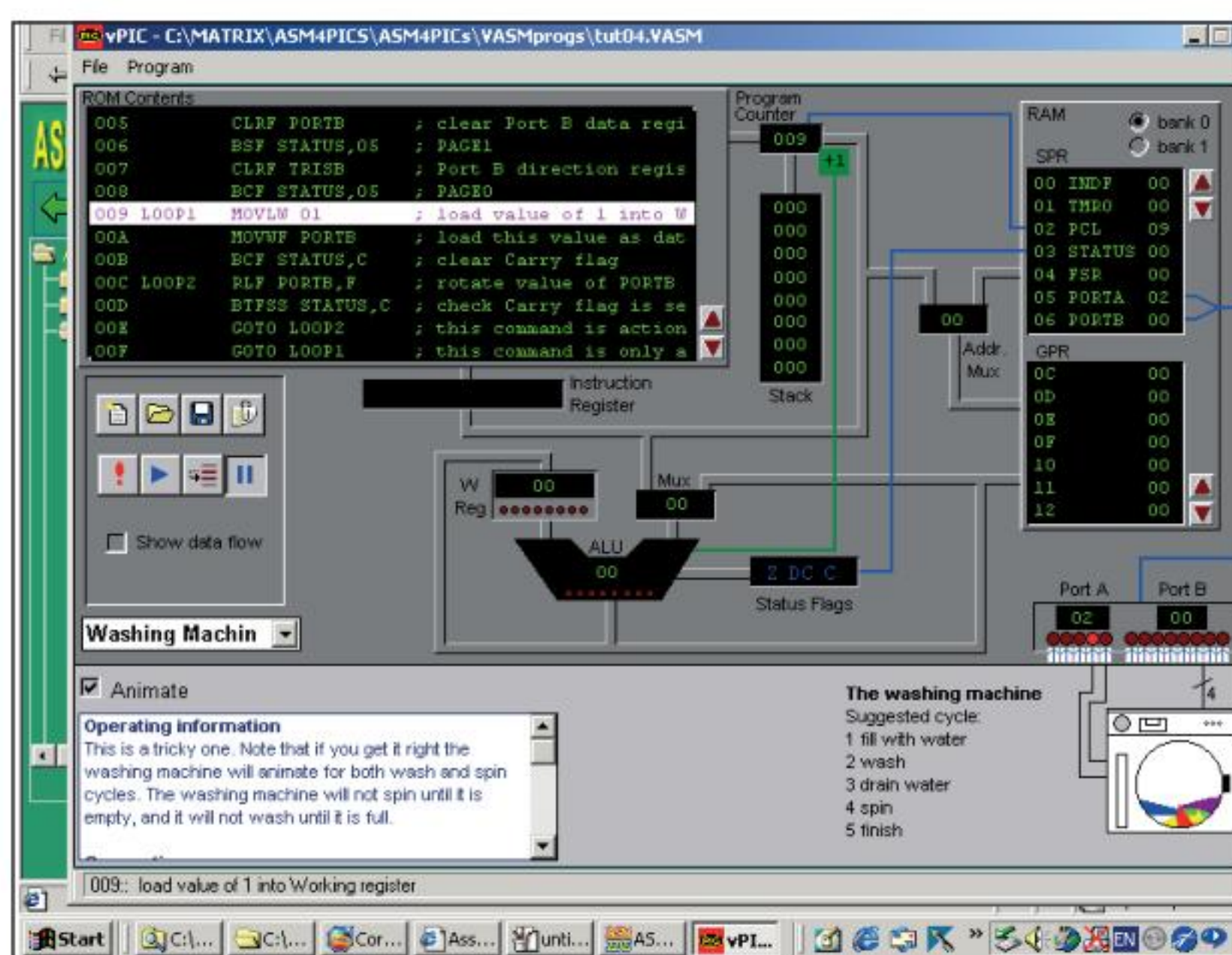
SOFTWARE

ASSEMBLY FOR PICmicro V6 (Formerly PICTutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICTutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

- Comprehensive instruction through 45 tutorial sections
- Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator
- Tests, exercises and projects covering a wide range of PICmicro MCU applications
- Includes MPLAB assembler
- Visual representation of a PICmicro showing architecture and functions
- Expert system for code entry helps first time users
- Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.)
- Imports MPASM files.

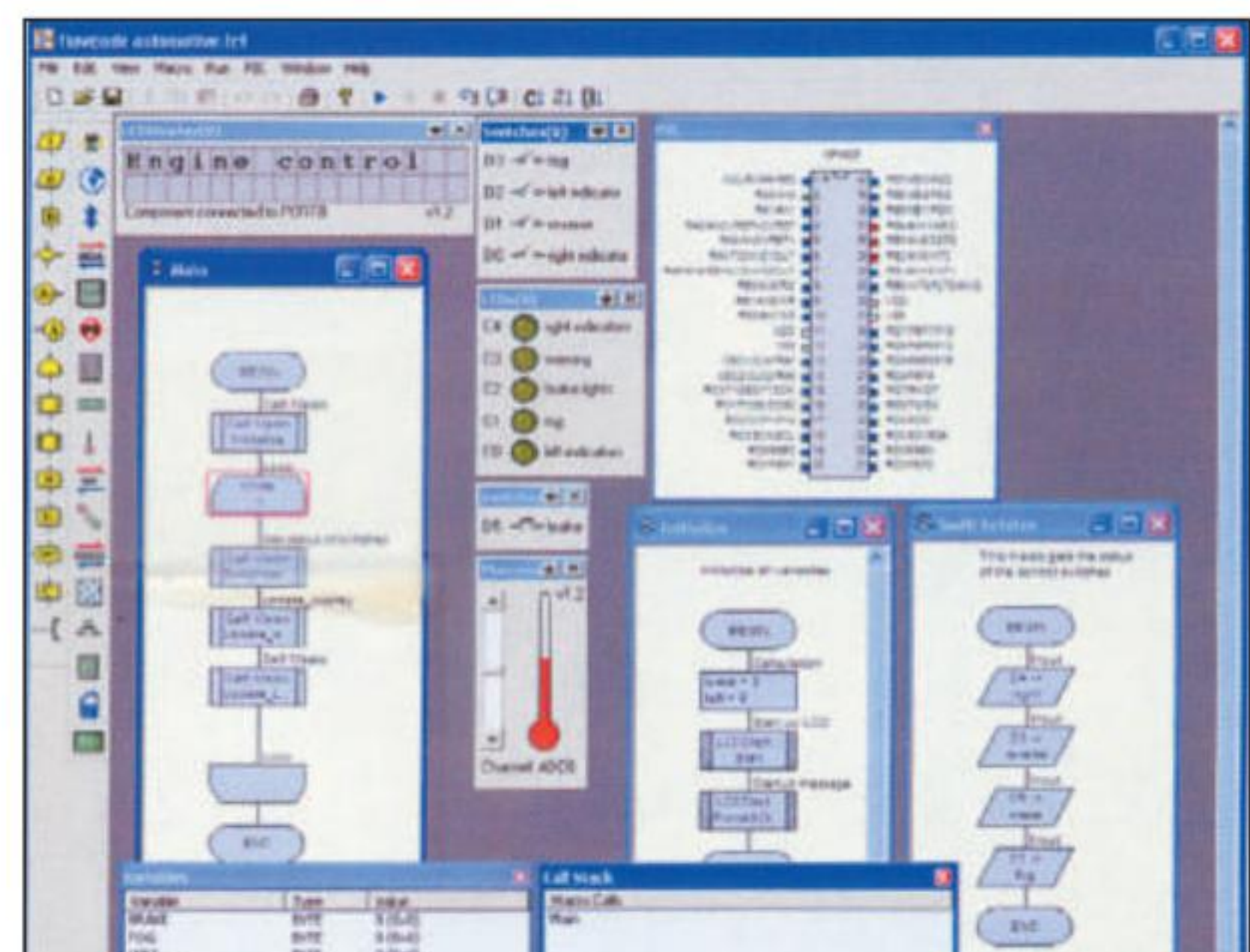


FLOWCODE FOR PICmicro V8

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces code for a wide range of devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



PRICES

Prices for each of the CD-ROMs above are:
(Order form on next page)

(UK and EU customers add VAT to 'plus VAT' prices)

Single License £99 plus VAT

Site Licence £499 plus VAT

Flowcode Contact us for pricing
(choose PIC-8b, PIC-16b, PIC-32b, AVR/Arduino, ARM)

ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programming language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

CD-ROM

Order code ETI2 CD-ROM

£9.50

ELECTRONICS TEACH-IN 3

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of *Teach-In 3* are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and identifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The *Teach-In 1* series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

CD-ROM

Order code ETI3 CD-ROM

£8.50

ELECTRONICS TEACH-IN 4

ELECTRONICS TEACH-IN 4 CD-ROM A BROAD-BASED INTRODUCTION TO ELECTRONICS.

The *Teach-In 4* CD-ROM covers three of the most important electronics units that are currently studied in many schools and colleges. These include, Edexcel BTEC level 2 awards and the electronics units of the Diploma in Engineering, Level 2.

The CD-ROM also contains the full *Modern Electronics Manual*, worth £29.95. The Manual contains over 800 pages of electronics theory, projects, data, assembly instructions and web links.

A package of exceptional value that will appeal to all those interested in learning about electronics or brushing up on their theory, be they hobbyists, students or professionals.

CD-ROM

Order code ETI4 CD-ROM

£8.99

ELECTRONICS TEACH-IN 5

ELECTRONICS TEACH-IN BUNDLE – FOR PARTS 3, 4 & 5

CD-ROM

Order code ETIB3 CD-ROM

£18.95

ORDERING ALL PRICES INCLUDE UK POSTAGE

Standard/Student/Basic (Hobbyist)
Version price includes postage to most countries
in the world EU residents outside the UK add £5 for
airmail postage per order



Please send me: CD-ROM ORDER FORM

- ☐ Assembly for PICmicro V6
☐ 'C' for 16 Series PICmicro V6

- Version required:
☐ Single Licence
☐ Site licence



Note: The software on each version is the same, only the licence for use varies.

- ☐ PICmicro Multiprogrammer Board and Development Board (hardware)

- ☐ Circuit Wizard – Standard
☐ Circuit Wizard – Professional
☐ GCSE Electronics
☐ TINA Design Suite V11 Basic (Hobbyist)
☐ TINA Design Suite V11 (Student)

- ☐ Teach-In 2
☐ Teach-In 3
☐ Teach-In 4
☐ Teach-In Bundle (3, 4 and 5)

Full name:

Address:

..... Post code: Tel. No:

Signature:

- ☐ I enclose cheque/PO in £ sterling payable to WIMBORNE PUBLISHING LTD for £
☐ Please charge my Visa/Mastercard: £

Valid From: Card expiry date:

Card No:

Card Security Code

(The last 3 digits on or just under the signature strip)

ELECTRONICS TEACH-IN 5 JUMP START

FREE
CD-ROM

15 design and build circuit projects dedicated to newcomers or those following courses in school and colleges. The projects are: Moisture Detector, Quiz Machine, Battery Voltage Checker, Solar-Powered Charger, Versatile Theft Alarm, Spooky Circuits, Frost Alarm, Mini Christmas Lights, iPod Speaker, Logic Probe, DC Motor Controller, Egg Timer, Signal Injector Probe, Simple Radio Receiver, Temperature Alarm.

PLUS:

PIC' N MIX – starting out with PIC Microcontrollers and PRACTICALLY SPEAKING – the techniques of project construction.

FREE CD-ROM – The free CD-ROM is the complete *Teach-In 2* book providing a practical introduction to PIC Microprocessors plus MikroElektronika, Microchip and L-Tek PoScope software.

160 Pages

Order code ETI5

£8.99

Single License and Site License Versions
– overseas readers add £5 to the basic price of each order for airmail postage (**do not add VAT** unless you live in an EU (European Union) country, then add VAT at 20% or provide your official VAT registration number).

Send your order to:
Direct Book Service
Wimborne Publishing Ltd
113 Lynwood Drive, Merley, Wimborne,
Dorset BH21 1UU

To order by phone ring

01202 880299. Fax: 01202 843233

Goods are normally sent within seven days

E-mail: fay.kearn@wimborne.co.uk

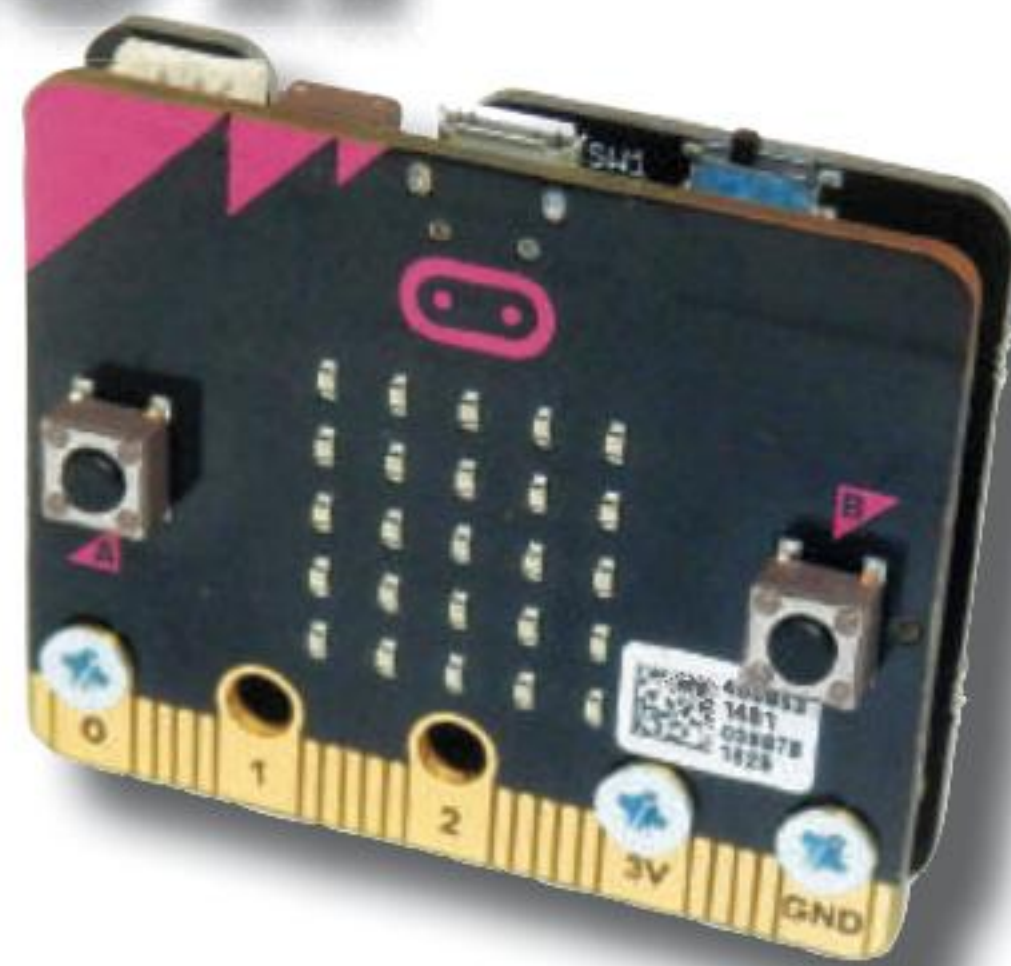
Online shop:

www.epemag.com

DIRECT BOOK SERVICE

Teach-In 2017

Introducing the BBC micro:bit



NEW



PYTHON CODING ON THE BBC MICRO:BIT

Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: The main features of the BBC micro:bit including a simulation in a Web browser screen; The various levels of programming languages; The Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; Scrolling messages, creating and animating images on the micro:bit's LEDs; Playing and creating music, sounds and synthesized speech; Using the on-board accelerometer to detect movement of the micro:bit on three axes; A glossary of computing terms.

This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages

Order code PYTH MBIT

£7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm x 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages

Order code BBC MBIT

£7.99

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Edition. Ian Sinclair

440 pages

Order code NE21

£33.99

STARTING ELECTRONICS – 4th Edition Keith Brindley

296 pages

Order code ELSEV100

£18.99

ELECTRONIC CIRCUITS – FUNDAMENTALS & APPLICATIONS – Updated version Mike Tooley

400 pages

Order code TF43

£32.99

FUNDAMENTAL ELECTRICAL AND ELECTRONIC PRINCIPLES – Third Edition C.R. Robertson

368 pages

Order code TF47

£21.99

A BEGINNER'S GUIDE TO TTL DIGITAL ICs R.A. Penfold

142 pages

OUT OF PRINT BP332

£5.45

UNDERSTANDING ELECTRONIC CONTROL SYSTEMS Owen Bishop

228 pages

Order code NE35

£36.99

The books listed have been selected by *Everyday Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door. Full ordering details are given on the last page.

FOR A FULL DESCRIPTION OF THESE BOOKS AND CD-ROMS SEE THE SHOP ON OUR WEBSITE

www.epemag.com

All prices include UK postage

MICROPROCESSORS

INTERFACING PIC MICROCONTROLLERS – SECOND EDITION Martin Bates

298 pages

Order code NE48

£34.99

PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C – LEARNING TO FLY THE PIC24 Lucio Di Jasio (Application Segments Manager, Microchip, USA)

496 pages +CD-ROM

Order code NE45

£38.00

INTRODUCTION TO MICROPROCESSORS AND MICROCONTROLLERS – SECOND EDITION John Crisp

222 pages

Order code NE31

£29.99

THE PIC MICROCONTROLLER YOUR PERSONAL INTRODUCTORY COURSE – THIRD EDITION. John Morton

270 pages

Order code NE36

£25.00

PIC IN PRACTICE (2nd Edition) David W. Smith

308 pages

Order code NE39

£24.99

MICROCONTROLLER COOKBOOK Mike James

240 pages

Order code NE26

£36.99

BOOK ORDERING DETAILS

All prices include UK postage. For postage to Europe (air) and the rest of the world (surface) please add £3 per book. Surface mail can take up to 10 weeks to some countries. For the rest of the world airmail add £4 per book. CD-ROM prices include VAT and/or postage to anywhere in the world. Send a PO, cheque, international money order (£ sterling only) made payable to **Direct Book Service** or card details, Visa or Mastercard to: **DIRECT BOOK SERVICE, WIMBORNE PUBLISHING LIMITED, 113 LYNWOOD DRIVE, MERLEY, WIMBORNE, DORSET BH21 1UU.**

Books are normally sent within seven days of receipt of order, but please allow 28 days for delivery – more for overseas orders. Please check price and availability (see latest issue of *Everyday Practical Electronics*) before ordering from old lists.

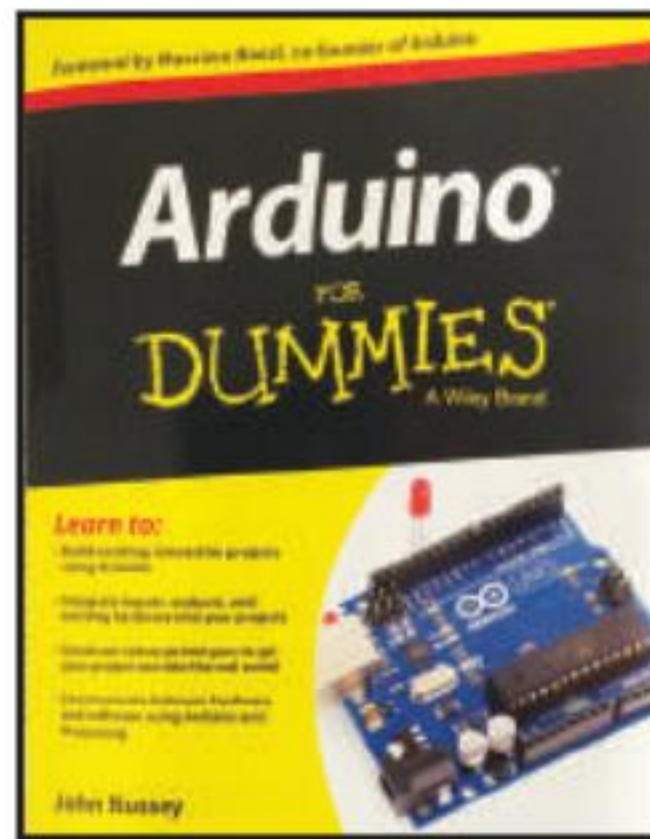
For a full description of these books please see the shop on our website.
Tel 01202 880299 Fax 01202 843233. E-mail: fay.kearn@wimborne.co.uk

Order from our online shop at: **www.epemag.com**



Teach-In 2016

Exploring the Arduino



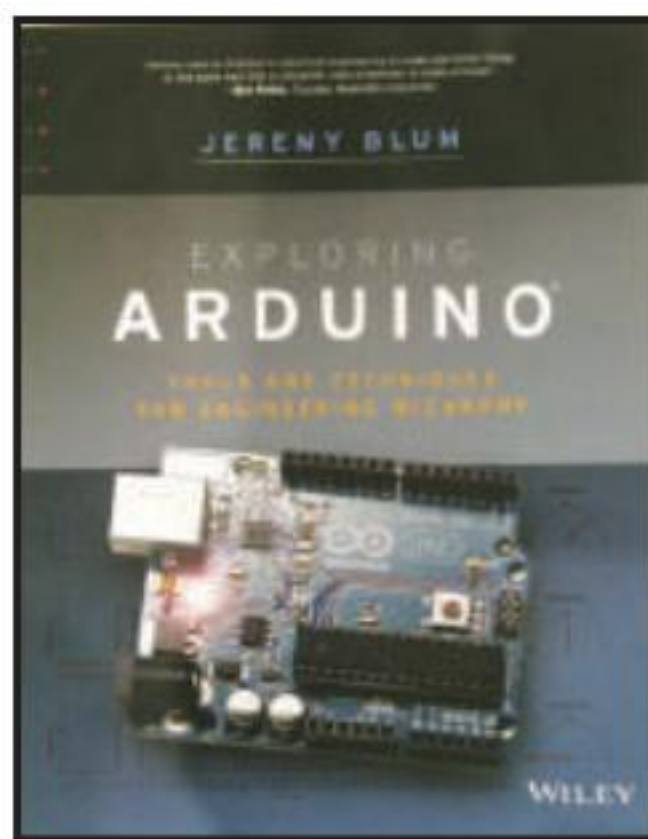
ARDUINO FOR DUMMIES

John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- **Learn by doing** – start building circuits and programming your Arduino with a few easy examples – right away!
- **Easy does it** – work through Arduino sketches line by line, and learn how they work and how to write your own.
- **Solder on!** – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
- **Kitted out** – discover new and interesting hardware to turn your Arduino into anything from a mobile phone to a Geiger counter.
- **Become an Arduino savant** – find out about functions, arrays, libraries, shields and other tools that let you take your Arduino project to the next level
- **Get social** – teach your Arduino to communicate with software running on a computer to link the physical world with the virtual world

438 Pages **Order code ARDDUM01** £19.99



EXPLORING ARDUINO

Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

- Explore the features of several commonly used Arduino boards
- Use the Arduino to control very simple tasks or complex electronics
- Learn principles of system design, programming and electrical engineering
- Discover code snippet, best practices and system schematics you can apply to your original projects
- Master skills you can use for engineering endeavours in other fields and with different platforms

357 Pages **Order code EXPARD01** £26.99

COMPUTING AND ROBOTICS

NEWNES INTERFACING COMPANION

Tony Fischer-Cripps

295 pages **Order code NE38** £41.00

HOW TO BUILD A COMPUTER MADE EASY

R.A. Penfold

120 pages **Order code BP707** £8.49

EASY PC CASE MODDING

R.A. Penfold

192 pages + CDROM **Order code BP542** £8.99

FREE DOWNLOADS TO PEP-UP AND PROTECT YOUR PC

R.A. Penfold

128 pages **Order code BP722** £7.99

WINDOWS XP EXPLAINED

N. Kantaris and P.R.M. Oliver

264 pages **Order code BP514** £7.99

THE INTERNET – TWEAKS, TIPS AND TRICKS

R. A. Penfold

128 pages **Order code BP721** £7.99

eBAY – TWEAKS, TIPS AND TRICKS

R. A. Penfold

128 pages **Order code BP716** £7.50

AN INTRODUCTION TO eBAY FOR THE OLDER GENERATION

Cherry Nixon

120 pages **Order code BP709** £8.49

HOW TO FIX YOUR PC PROBLEMS

R.A. Penfold

128 pages **Order code BP705** £8.49

AN INTRODUCTION TO WINDOWS VISTA

P.R.M. Oliver and N. Kantarris

120 pages **Order code BP703** £8.49

WINDOWS 8.1 EXPLAINED

180 Pages **Order code BP747** £10.99

WINDOWS 8.1 EXPLAINED

180 Pages **Order code BP747** £10.99

COMPUTING FOR THE OLDER GENERATION

Jim Gatenby

308 pages **Order code BP601** £8.99

ANDROIDS, ROBOTS AND ANIMATRONICS

Second Edition – John Iovine

224 pages **Order code MGH1** £16.99

ROBOT BUILDERS COOKBOOK

Owen Bishop

366 pages **Order code NE46** £26.00

INTRODUCING ROBOTICS WITH LEGO

MINDSTORMS

Robert Penfold

288 pages + **Order code BP901** £14.99

MORE ADVANCED ROBOTICS WITH LEGO

MINDSTORMS – Robert Penfold

298 pages **Order code BP902** £14.99

HOW TO FIX YOUR PC PROBLEMS

R. A. Penfold

128 pages **Order code BP705** £8.49

WINDOWS 7 – TWEAKS, TIPS AND TRICKS

Andrew Edney

120 pages **Order code BP708** £8.49

GETTING STARTED IN COMPUTING FOR THE OLDER GENERATION

Jim Gatenby

120 pages **Order code BP704** £8.49

WINDOWS 8.1 EXPLAINED

Noel Kantaris

180 Pages **Order code BP747** £10.99

COMPUTING WITH A LAPTOP FOR THE OLDER GENERATION

R.A. Penfold

120 pages **Order code BP702** £8.49

AN INTRODUCTION TO EXCEL SPREADSHEETS

Jim Gatenby

18 pages **Order code BP701** £8.49

AN INTRODUCTION TO THE NEXUS 7

118 Pages **Order code BP744** £8.99

KINDLE FIRE HDX EXPLAINED

118 Pages **Order code BP743** £8.99

AUDIO & VIDEO

VALVE AMPLIFIERS – 4th Edition

Morgan Jones

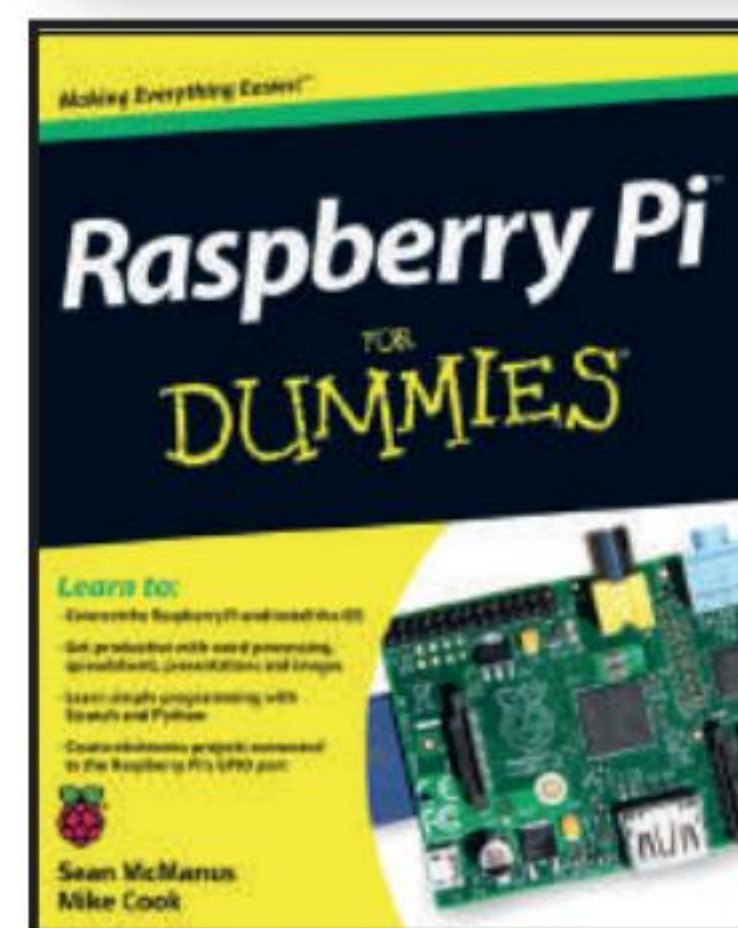
288 pages **Order code ELSEV33** £46.99

BUILDING VALVE AMPLIFIERS

Morgan Jones

368 pages **Order code NE40** £29.00

RASPBERRY PI



RASPBERRY PI FOR DUMMIES

Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

400 Pages **Order code RPiDUM01** £17.99

RASPBERRY PI MANUAL: A practical guide to the revolutionary small computer

176 pages **Order code H001** £17.99

RASPBERRY PI USER-GUIDE – 4th Edition

262 pages **Order code JW001** £20.90

PROGRAMMING THE RASPBERRY PI

192 pages **Order code MGH4** £10.99

GETTING STARTED WITH RASPBERRY PI

164 pages **Order code OR01** £11.50

TEACH-IN BOOKS

ELECTRONICS TEACH-IN 6



ONLY AVAILABLE ON CDROM

ELECTRONICS TEACH-IN 6 – A COMPREHENSIVE GUIDE TO RASPBERRY PI Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.

160 Pages **Order code ETI6** £8.99

ELECTRONICS TEACH-IN 7 (Includes free CDROM)



ELECTRONICS TEACH-IN 7 – DISCRETE LINEAR CIRCUIT DESIGN Mike & Richard Tooley

Teach-In 7 is a complete introduction to the design of analogue electronic circuits. Ideal for everyone interested in electronics as a hobby and for those studying technology at schools and colleges. Supplied with a free Cover-Mounted CDROM containing all the circuit software for the course, plus demo CAD software for use with the Teach-In series'

Discrete Linear Circuit Design* Understand linear circuit design* Learn with 'TINA' – modern CAD software* Design simple, but elegant circuits* Five projects to build: Pre-amp, Headphone Amp, Tone Control, VU-meter, High Performance Audio Power Amp. PLUS *Audio Out* – an analogue expert's take on specialist circuits; *Practically Speaking* – the techniques of project building

160 Pages **Order code ETI7** £8.99

ELECTRONICS TEACH-IN 8 (Includes free CDROM)



ELECTRONICS TEACH-IN 8 – INTRODUCING THE ARDUINO Mike & Richard Tooley

Hardware – learn about components and circuits; Programming – powerful integrated development system; Microcontrollers – understand control operations; Communications – connect to PCs and other Arduinos

This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The Free CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

160 Pages **Order code ETI8** £8.99

CHECK OUT OUR WEBSITE FOR MORE BOOKS
WWW.EPEMAG.COM

BOOK ORDER FORM

Full name:

Address:

.....

.....

..... Post code: Telephone No:

Signature:

☐ I enclose cheque/PO payable to DIRECT BOOK SERVICE for £

☐ Please charge my card £ Card expiry date.....

Card Number

Valid From Date Card Security Code (The last three digits on or just below the signature strip)

Please send book order codes:

.....

Please continue on separate sheet of paper if necessary

THE BASIC SOLDERING GUIDE HANDBOOK

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

The No.1 resource to learn all the basic aspects of electronics soldering by hand.

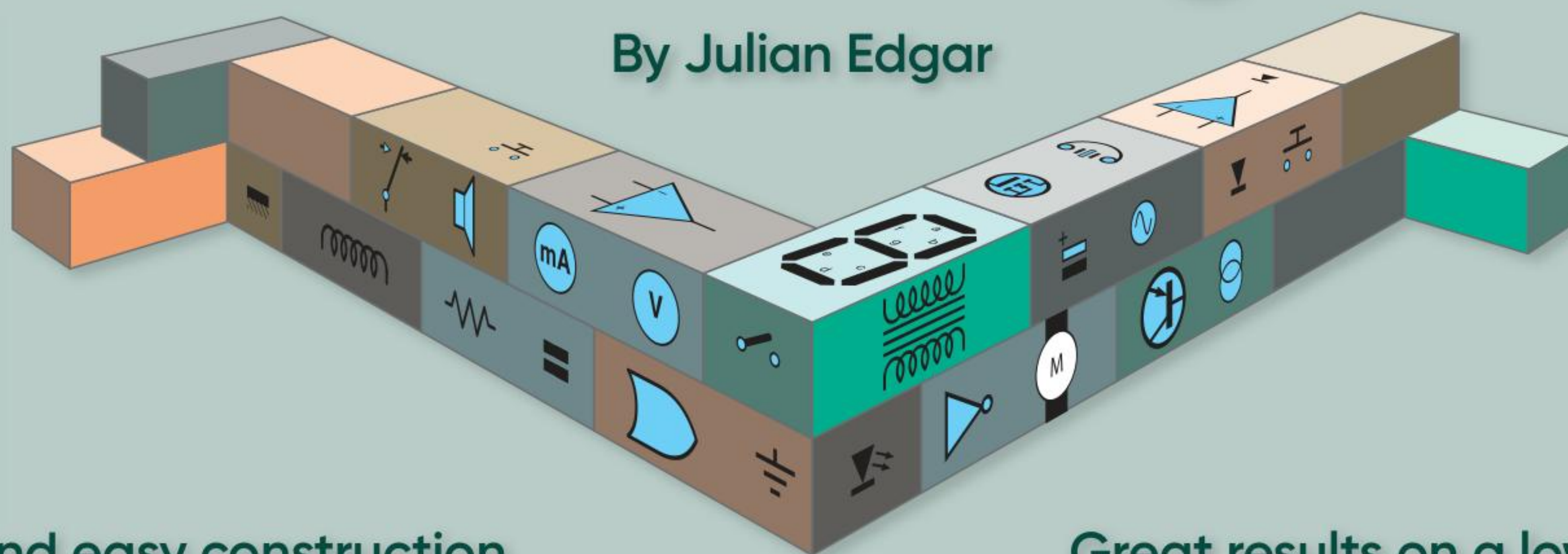
With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on Reflow Soldering and Desoldering Techniques, Potential Hazards and Useful Resources. Plus a Troubleshooting Guide.

Also ideal for those approaching electronics from other industries, the Basic Soldering Guide Handbook is the best resource of its type, and thanks to its excellent colour photography and crystal clear text, the art of soldering can now be learned by everyone!

86 Pages **Order code AW1** £9.99

Electronic Building Blocks

By Julian Edgar



Quick and easy construction

Great results on a low budget

K-Type Thermocouple Display

Here's one little module that I am really excited about. Why? Well, for years I have been using thermocouple displays – those that can measure really high temperatures. Way back when, I fitted an analogue (yes, analogue!) thermocouple display to one of my turbocharged cars, so that I could read exhaust gas temperature. (Too high a temperature and you could melt turbine blades.) It was an expensive instrument, but worth the protection it afforded. Then, 10 or 15 years later, I worked with an electronics magazine to develop a digital thermocouple kit. It was cheaper than the old analogue gauge, but still cost a hefty amount – and took quite some calibration.

But let's fast forward to the present. Here we have a digital thermocouple display that costs under £6 delivered! Unbelievable! It's available from Banggood (ID: 1031834) and comes complete with a screw-in type probe on 450mm of cable. (The thermocouple connects to the meter via spade terminals, so it's easy to add a separately purchased

probe with a longer cable – more on this in a moment.)

So before we look at the unit in more detail, what can you use it for? Well, I've already covered one use – exhaust gas temperature measurements. It doesn't have to be on a car; it can also be used to measure flue gas temperature on a wood-fired heater (expect to see flue temperatures in the 200-300°C range).

More broadly, a K-type thermocouple can be used wherever temperatures exceed commonly available thermistor-based thermometers – that's typically temperatures above 110°C. So – and again an automotive example – you can measure engine oil temperatures and automatic transmission oil temperatures. Electric motor windings are also sometimes rated for operation of up to 155°C, and transformers can be designed to operate at quite high temperatures. On the domestic front, the sensor can also be used in espresso machines and pizza ovens.

Thermocouples

Thermocouples are sensors that use two dissimilar metal wires. At one end, called the 'hot' junction, the wires are welded together. This junction is placed at the location where temperature is being measured. At the other end of the cable, the cold junction, the cable is maintained at a known temperature – often the melting point of ice. A tiny voltage is generated when the hot junction is exposed to a temperature that is different to the cold junction. Because it's a bit unwieldy carrying around instruments equipped with ice baths, the reference temperature is normally corrected electronically – this is called 'cold junction compensation'.

Different types of thermocouples

The supplied thermocouple uses an M6 fitting on 450mm of cable, but if this doesn't suit, other thermocouples with different physical shapes and cable lengths can be easily used.



use different pairs of dissimilar metals. The common K-type thermocouple – as used with this meter – is made from chromel and alumel. Chromel is an alloy of nickel and chromium, while alumel is made from nickel, aluminium, manganese and silicon. A K-type thermocouple has a sensitivity of approximately 41µV/°C. Other types of thermocouples include types E, J, M, N and T. All have different output characteristics, so the thermocouple type needs to be matched to the meter.

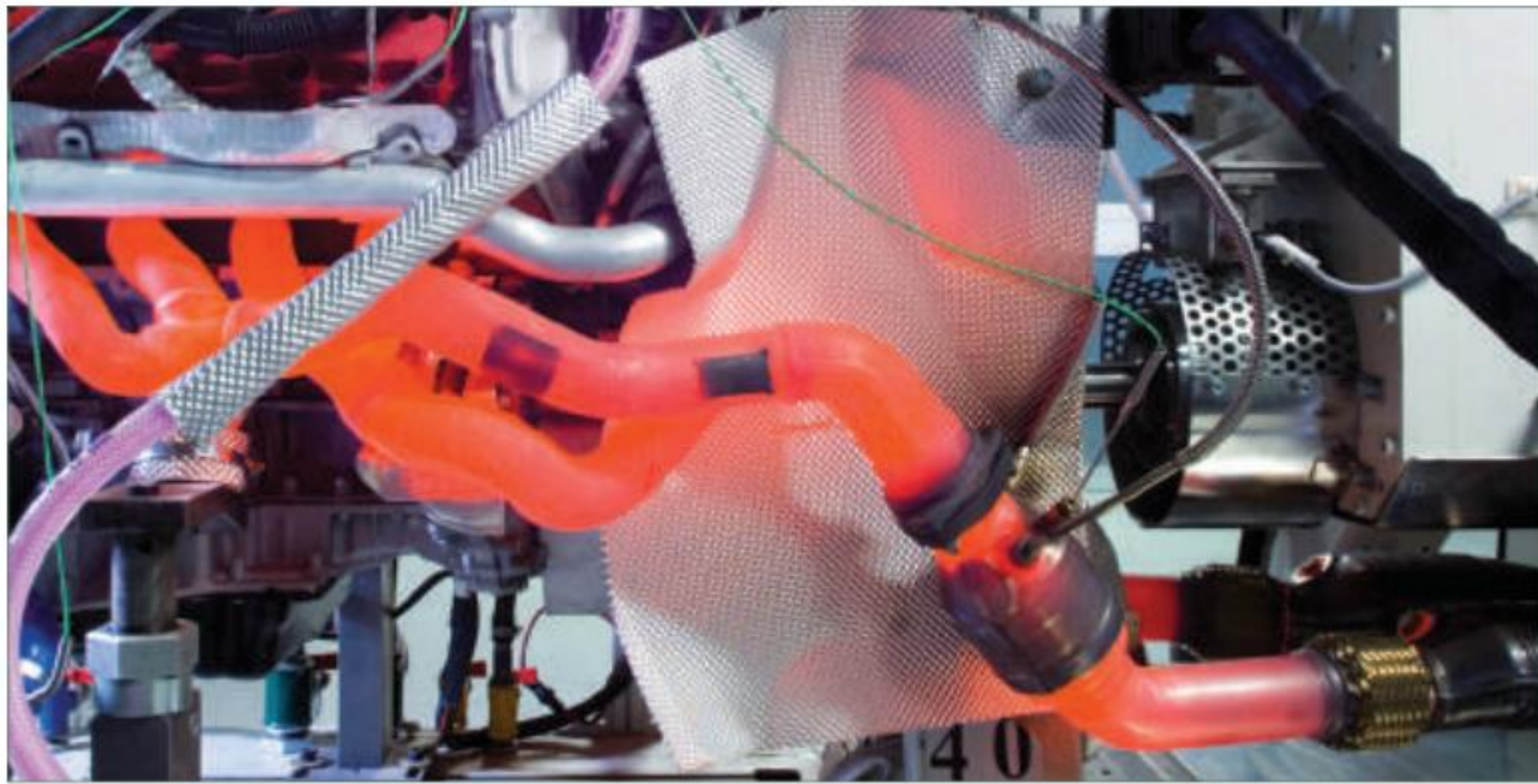
Thermocouples are also available in different physical shapes and sizes. The thermocouple supplied with this meter comprises a rounded knob about the size of a match head, mounted in a threaded M6 fitting. If, for example, you wished to measure the temperature of flue gases, you could drill a hole in the flue and then insert an M6 'rivnut'



The rear of the meter shows the terminal block connections for the thermocouple. Power for the meter is nominally 12V.



The K-Type thermocouple meter uses a panel-mount red LED display, supplied with the pictured thermocouple. You can measure temperatures up to 999°C!



Measuring high temperatures – thermocouples used in a red-hot engine exhaust on a dynamometer testbed. (Image courtesy of Audi)

(a device that then becomes a captive nut). Screw the probe into place, attach the meter and power, and you're finished.

However, such a probe has fairly large thermal mass, and so the probe won't change in temperature quickly, even if the actual temperature is rapidly changing. If fast reaction is important, you can use a bead thermocouple that comprises just the tiny blob of the welded wires. This type of thermocouple will change in temperature very rapidly indeed – but, it will be less durable (shorter lifespan) at high temperatures. You can also buy slim, pointy probes – and even special washers that can be placed under spark plugs, so you can measure engine cylinder head temperature.

Cables and connectors – get it right!

Probes are also available with a variety of cable lengths, and with the cable covered in plastic or equipped with a durable stainless steel braided outer cover. One very important point – do buy a thermocouple with the correct length cable. Don't do what I once did, and try to extend the thermocouple wiring using normal copper cable. I even added a (normal copper-based) rotary switch that could select different thermocouples! Why was there a problem? Well, each termination had effectively its own cold junction, and each was varying all over the place in temperature! The temperature readings were weird, to say the least... Instead of that approach, buy thermocouple cables of the right length that use proper thermocouple-matched spade terminals, allowing direct connection to the meter. (If you must extend your thermocouple cable length then not only must you use exactly the right extension cable, but also the correct thermocouple connectors – and they must all be wired up with the right polarity. It's surprisingly complicated and very easy to get wrong. Again, the best advice is, wherever possible, buy a thermocouple with the length of cable you need and always use the supplied connectors/terminals.)

Fortunately, thermocouples are now incredibly cheap. I remember having to go to a specialist supplier and paying something like £25 for just one thermocouple. Now they're one-tenth of that price – and in addition to stocking the meter, Banggood has a good range of K-type thermocouples.

The meter

The 48 × 29 × 26mm panel-mount meter has red LEDs and uses a nominal supply voltage of 12V; although I dropped it to 6V and the meter stayed accurate. The display shows temperatures to one decimal place up to of 99.9°C, and in full units above that to 999°C. Update is quite fast, at around 3Hz. Accuracy seemed good – and certainly sufficient for general-purpose use.

Cold junction compensation occurs via a sensor positioned off the PCB and located – appropriately enough – next to the terminal block where the thermocouple connects. If this sensor is warmed at a different rate to the terminal block, the meter's reading will be in error. This can be easily seen by placing your warm fingers on the sensor and watching the display change,

even though the remote thermocouple hot junction temperature has not altered. The meter should, therefore, be located so the temperature of the meter as a whole varies – rather than the cold-junction sensor being located near to a heat-dissipating resistor in other circuitry, for example.

I had to wait five months before the meter was in stock at Banggood, such is the demand for it. At the time of writing well over 1000 units have been sold – this is the one to get!

Next month

In April 2019's *Electronic Building Blocks* we'll make a very effective human-powered LED torch using only off-the-shelf components.





Laser

Why tolerate when you can automate?



X-10 Home Automation



KAT5 KAT5 AV transmission and IR control system



C-Bus Shop
C-Bus and C-Bus Wireless



BARIX Barix Ethernet based MP3, communications and control systems

www.cbus-shop.com

www.laser.com

Integrators, Installers, Trade and Retail customers welcome

Laser Business Systems Ltd
Tel: +44 (0) 20 8441 9788
Fax: +44 (0) 20 8449 0430
Email: info@laser.com
16 Garthland Drive, EN5 3BB



CRICKLEWOOD ELECTRONICS
Established 1981

Your best bet since MAPLIN
Chock-a-Block with Stock

Visit: www.cricklewoodelectronics.com

Or phone our friendly knowledgeable staff on **020 8452 0161**

Components • Audio • Video • Arduino • Connectors • Cables • CCTV • Leads • Tools & Test Equipment etc, etc



Visit our Shop, Call or Buy online at:
www.cricklewoodelectronics.com

020 8452 0161

Visit our shop at:
40-42 Cricklewood Broadway
London NW2 3ET

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevant project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com.** Cheques should be crossed and made payable to *Everyday Practical Electronics* (Payment in £ sterling only).

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

PROJECT TITLE	ORDER CODE	COST
APRIL '17		
Microwave Leakage Detector	04103161	£8.00
Arduino Multifunctional 24-bit Measuring Shield – RF Head Board	04116011 } 04116012	£17.75
Battery Pack Cell Balancer	11111151	£9.00
MAY '17		
The Micromite LCD BackPack	07102122	£11.25
Precision 230V/115V 50/60Hz Turntable Driver	04104161	£19.35
JUNE '17		
Ultrasonic Garage Parking Assistant	07102122	£10.45
Hotel Safe Alarm	03106161	£8.00
100dB Stereo LED Audio Level/VU Meter	01104161	£17.75
JULY '17		
Micromite-Based Super Clock	07102122	£10.45
Brownout Protector for Induction Motors	10107161	£12.90
AUG '17		
Micromite-Based Touch-screen Boat Computer with GPS	07102122	£10.45
Fridge/Freezer Alarm	03104161	£8.00
SEPT '17		
Compact 8-Digit Frequency Meter	04105161	£12.88
NOV '17		
50A Battery Charger Controller	11111161	£12.88
Micropower LED Flasher (45 □ 47mm)	16109161	£8.00
(36 □ 13mm)	16109162	£5.60
Phono Input Converter	01111161	£8.00
DEC '17		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
JAN '18		
High-Power DC Motor Speed Controller – Part 1	11112161	£12.88
Build the SC200 Amplifier Module	01108161	£12.88
FEB '18		
GPS-Synchronised Analogue Clock Driver	04202171	£12.88
High-Power DC Motor Speed Controller – Part 2		
– Control Board	11112161	£12.88
– Power Board	11112162	£15.30
MARCH '18		
Stationmaster	09103171 } 09103172	£17.75
Build the SC200 Amplifier Module		
– Power Supply	01109111	£16.45
APRIL '18		
Spring Reverberation Unit	01104171	£15.30
DDS Sig Gen Lid	Black	£8.05
DDS Sig Gen Lid	Blue	£7.05
DDS Sig Gen Lid	Clear	£8.05
MAY '18		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£10.45
Microbridge	24104171	£5.60
JUNE '18		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£15.30

PROJECT TITLE	ORDER CODE	COST
JULY '18		
Touchscreen Appliance Energy Meter – Part 1	04116061	£17.75
Automotive Sensor Modifier	05111161	£12.88
AUG '18		
Universal Temperature Alarm	03105161	£7.05
Power Supply For Battery-Operated Valve Radios	18108171 } 18108172 } 18108173 } 18108174 }	£27.50
SEPT '18		
3-Way Active Crossover	01108171	£22.60
Ultra-low-voltage Mini LED Flasher	16110161	£5.60
OCT '18		
6GHz+ Touchscreen Frequency Counter	04110171	£12.88
Two 230VAC MainsTimers	10108161 } 10108162 }	£12.88
NOV '18		
Super-7 AM Radio Receiver	06111171	£27.50
FEB '19		
1.5kW Induction Motor Speed Controller	10105122	£35.00
MARCH '19		
10-LED Bargraph	04101181	£11.25
Main Board	04101182	£8.60
Processing Board		

Back numbers or photocopies of articles are available if required – see the **Back Issues** page for details. **WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.**

* See NOTE left regarding PCBs with eight digit codes *

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.
Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
www.epemag.com

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email fay.kearn@wimborne.co.uk stating which masters you would like.

EPE PRINTED CIRCUIT BOARD SERVICE

Order Code	Project	Quantity	Price
.....			
Name			
Address			
.....			
Tel. No.			
I enclose payment of £ (cheque/PO in £ sterling only)			
to: Everyday Practical Electronics			
 			
Card No.			
Valid From Expiry Date			
Card Security No.			
Signature			
Note: You can also order PCBs by phone, Fax or Email or via the Shop on our website on a secure server: http://www.epemag.com			





CLASSIFIED

ADVERTISEMENTS

If you want your advertisements to be seen by the largest readership at the most economical price our classified page offers excellent value. The rate for semi-display space is £10 (+VAT) per centimetre high, with a minimum height of 2.5cm. All semi-display adverts have a width of 5.5cm. The prepaid rate for classified adverts is 40p (+VAT) per word (minimum 12 words).

All cheques, postal orders, etc., to be made payable to Everyday Practical Electronics. **VAT must be added.** Advertisements, together with remittance, should be sent to Everyday Practical Electronics Advertisements, 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU. Phone: 01202 880299. Fax: 01202 843233. Email: stewart.kearn@wimborne.co.uk. For rates and information on display and classified advertising please contact our Advertisement Manager, Stewart Kearn as above.

Everyday Practical Electronics reaches more UK readers than any other UK monthly hobby electronics magazine, our sales figures prove it.

We have been the leading monthly magazine in this market for the last twenty-seven years.

BOWOOD ELECTRONICS LTD

Suppliers of Electronic Components

www.bowood-electronics.co.uk

Unit 10, Boythorpe Business Park, Dock Walk, Chesterfield, Derbyshire S40 2QR. Sales: 01246 200 222

Send large letter stamp for Catalogue

The British Amateur Electronic Club at:

baec.tripod.com

Has many interesting articles on computers; digital electronics and analogue electronics.



COAST ELECTRONICS

BREAKOUTS-COMPONENTS-
CONTRACT DESIGN-3D PRINTER PARTS-
MUSICAL-MICROCONTROLLERS
WWW.COASTELECTRONICS.CO.UK

MISCELLANEOUS

PIC DEVELOPMENT KITS, DTMF kits and modules, CTCSS Encoder and Decoder/Display kits. Visit www.cstech.co.uk

VALVES AND ALLIED COMPONENTS IN STOCK. Phone for free list. Valves, books and magazines wanted. Geoff Davies (Radio), tel. 01788 574774.

Andrew Kenny – Qualified Patent Agent
EPO UKIPO USPTO

Circuits Electric Machinery Mechatronics

Web: www.akennypatentm.com

Email: Enquiries@akennypatentm.com

Tel: 0789 606 9725

ADVERTISERS INDEX

CRICKLEWOOD ELECTRONICS	77
ESR ELECTRONIC COMPONENTS	55
HAMMOND ELECTRONICS Ltd	9
JPG ELECTRONICS	80
LASER BUSINESS SYSTEMS	77
MICROCHIP	Cover (ii), Cover (iii) & 5
PEAK ELECTRONIC DESIGN	Cover (iv)
POLABS D.O.O.	63
QUASAR ELECTRONICS	2
SOUNDTRONICS	3
STEWART OF READING	22
TAG-CONNECT	55

ADVERTISEMENT OFFICES:

113 LYNWOOD DRIVE, MERLEY, WIMBORNE,
DORSET BH21 1UU

PHONE: 01202 880299

FAX: 01202 843233

EMAIL: stewart.kearn@wimborne.co.uk

WEB: www.epemag.com

For editorial address and phone numbers see page 7

Next Month – in the April issue

Internet GPS Time Source

GPS-based clocks are great, but what if you can't get a GPS signal? This clever alternative lets you use a cheap Wi-Fi module to act as a time reference – kept accurate via the Internet.

Infrared Sensing Heater Controller

This *Heater Controller* allows you to select exactly how much warmth you want from the heater and it can even be fitted with a thermopile sensor for precise temperature control.

Low-cost Electronic Modules – Part 15

Next month, we look at the popular *ESP-01 Wi-Fi Data Transceiver*; designed to allow almost any microcontroller to connect to Wi-Fi.

Teach-In 2019 – Part 5

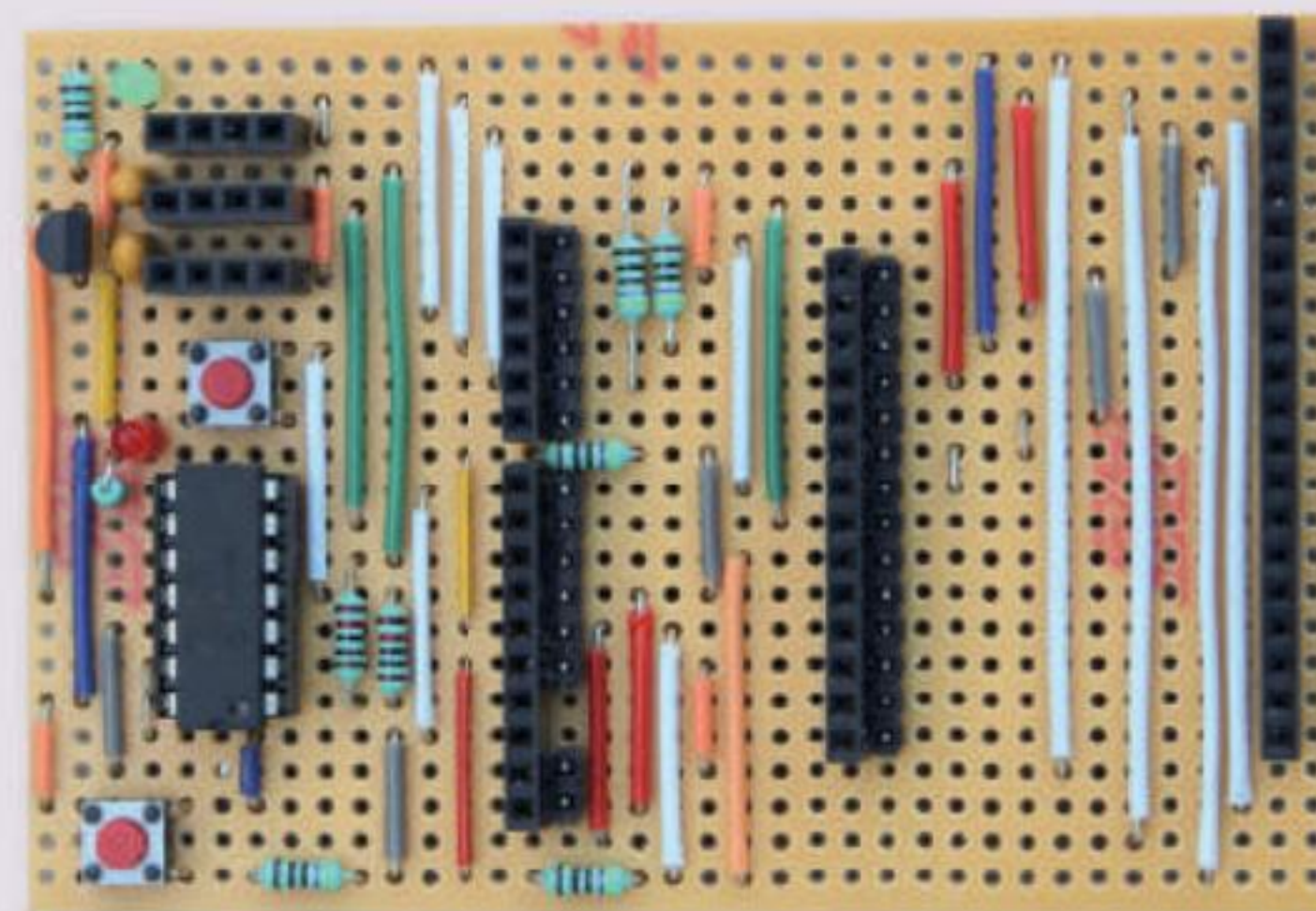
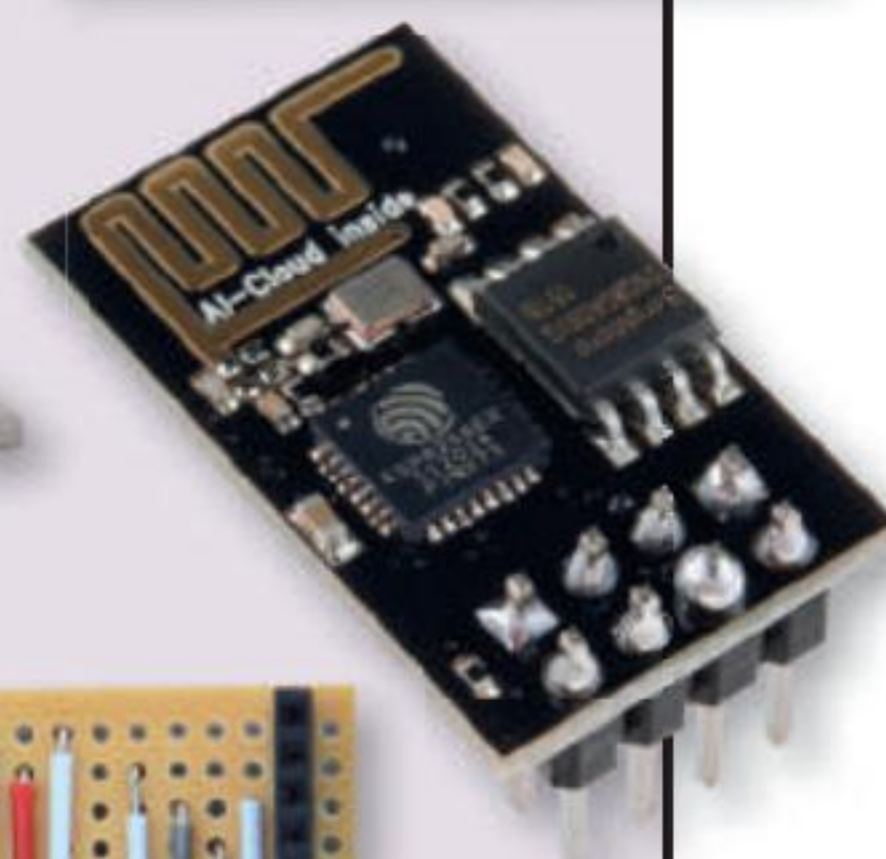
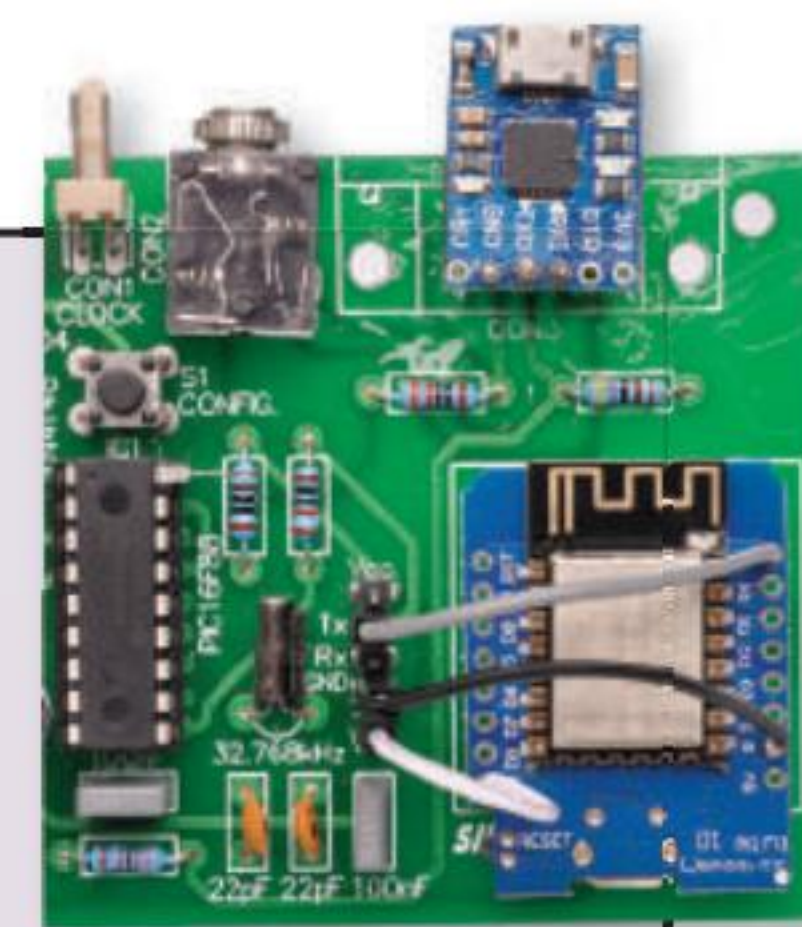
In *Part 5* of *Teach-In 2019* we will explore switched-mode controllers in greater detail and our *Practical Project* will be a secondary SMPS that provides a regulated output.

Make it with Micromite – Part 3

We've built the *Micromite Keyring Computer (MKC)*; now it's time to build the accompanying *Development Module* that will allow us to configure the *MKC* for different projects and applications.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks*, *PIC n' Mix*, *Techo Talk* and *Net Work*.



On sale 7 March 2019

Content may be subject to change

WELCOME TO JPG ELECTRONICS

Selling Electronics in Chesterfield for 29 Years

**Open Monday to Friday 9am to 5:30pm
And Saturday 9:30am to 5pm**

- Aerials, Satellite Dishes & LCD Brackets
- Audio Adaptors, Connectors & Leads
- BT, Broadband, Network & USB Leads
- Computer Memory, Hard Drives & Parts
- DJ Equipment, Lighting & Supplies
- Extensive Electronic Components
 - ICs, Project Boxes, Relays & Resistors
- Raspberry Pi & Arduino Products
- Replacement Laptop Power Supplies
- Batteries, Fuses, Glue, Tools & Lots more...



T: 01246 211 202

E: sales@jpgelectronics.com

**JPG Electronics, Shaw's Row,
Old Road, Chesterfield, S40 2RB**

W: www.jpgelectronics.com



Retail & Trade Welcome • Free Parking • Google St View Tour: S40 2RB

Calling all EPE subscribers

If you are one of our valued subscribers then please note that we have changed the way we send subscription renewal reminders.

Instead of sending you a renewal card, we now print a box on the address sheet that comes with your copy of EPE.

This box will advise you of the last issue of your current subscription.

To renew, you have three easy choices:

1. Call us on: 01202 880299
2. Visit our website at: www.epemag.com
3. Send a cheque with your details to:

**Electron Publishing Limited
Subscriptions
113 Lynwood Drive
Merley
Wimborne
Dorset BH21 1UU**

Published on approximately the first Thursday of each month by Electron Publishing Limited, 1 Buckingham Road, Brighton, East Sussex BN1 3RA. Printed in England by Acorn Web Offset Ltd., Normanton WF6 1TW. Distributed by Seymour, 86 Newman St., London W1T 3EX. Subscriptions INLAND: £25.00 (6 months); £47.00 (12 months); £89.00 (2 years). EUROPE: airmail service, £30.00 (6 months); £56.00 (12 months); £107.00 (2 years). REST OF THE WORLD: airmail service, £37.00 (6 months); £70.00 (12 months); £135.00 (2 years). Payments payable to 'Everyday Practical Electronics', Subs Dept, Electron Publishing Limited. Email: subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

Faster Programming, Wider Voltage Ranges and Enhanced Interface Options

PICkit™ 4 enables faster design development



With five times faster programming and a wider 1.2V to 5V range, the Microchip MPLAB® PICkit™ 4 Development Tool supports low-cost development of even more Microchip controllers.

PICkit™ 4 also introduces improved USB connectivity with a hi-speed USB 2.0 interface and advanced debugging over 4-wire JTAG and serial wire debug with streaming data gateway in addition to legacy interfaces.

The new advanced interfaces support in-circuit programming and debugging of Microchip's CEC1702 hardware cryptography-enabled MCUs, in addition to dsPIC® Digital Signal Controllers and PIC® microcontrollers from 8- to 32-bit.



www.microchip.com/PICkit4eu

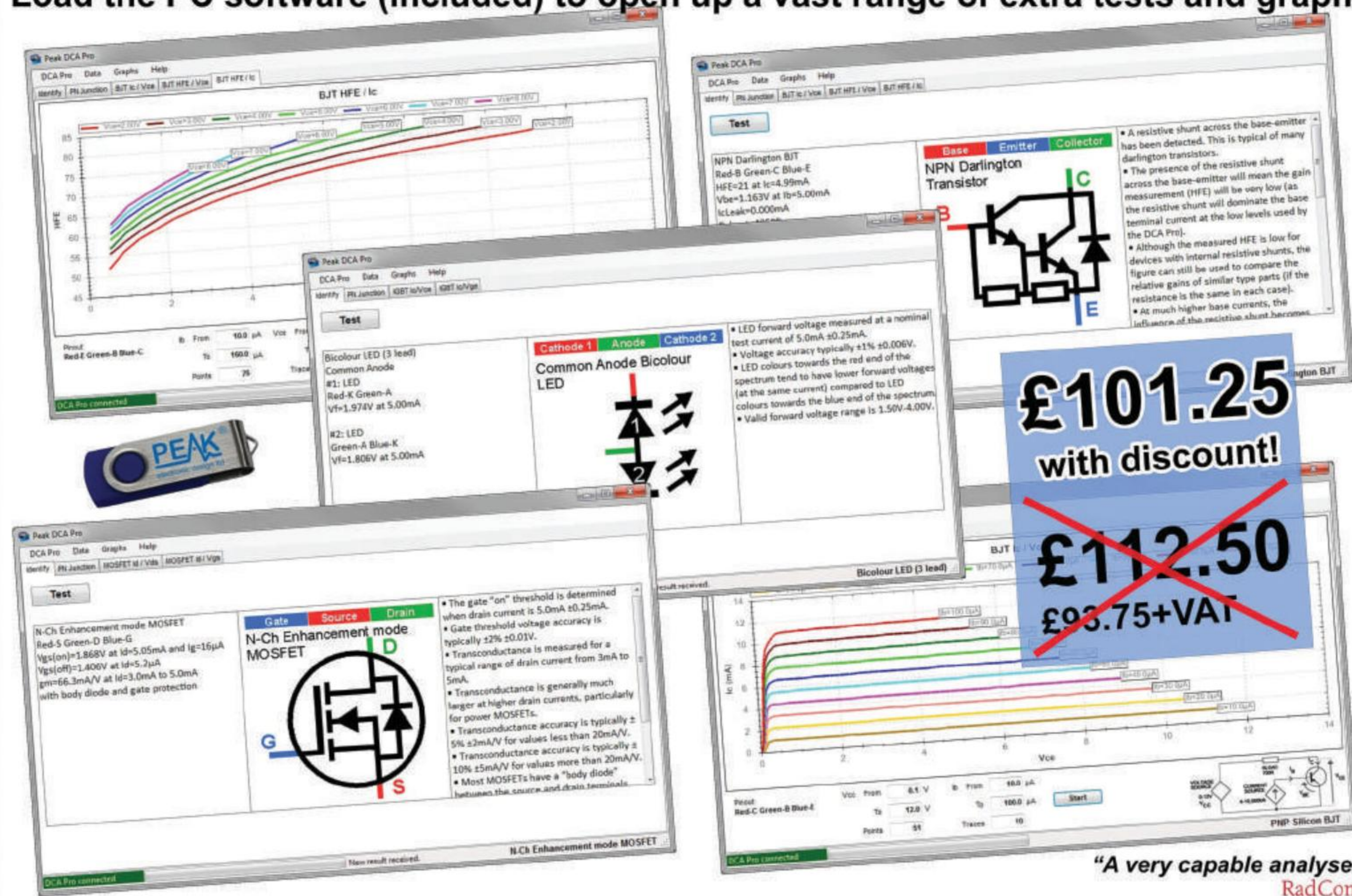
DCA75

Advanced Semiconductor Analyser and Curve Tracer



A versatile instrument that you'll love using for testing a huge range of semiconductor components. Supports MOSFETs, transistors, diodes, LEDs, JFETs, IGBTs and more. Connect any way round and let the **DCA Pro** identify the component type, pinout and lots of parameters. Can be used standalone or connected to a Windows® PC (XP up to Win10).

Load the PC software (included) to open up a vast range of extra tests and graphs.



"A very capable analyser"
RadCom

It's only possible to show summary specifications here. Please ask if you'd like detailed data. Further information is also available on our website. Product price refunded if you're not happy.

Tel. 01298 70012
www.peakelec.co.uk
sales@peakelec.co.uk

Atlas House, 2 Kiln Lane
Harpur Hill Business Park
Buxton, Derbyshire
SK17 9JL, UK

